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This handbook for the port of Barcelona, one in a series of severe weather guides for Mediterranean ports, provides decision-making guidance for ship captains whose vessels are threatened by actual or forecast strong winds, high seas, restricted visibility or thunderstorms in the port vicinity. Causes and effects of such hazardous conditions are discussed. Precautionary or evasive actions are suggested for various vessel situations. The handbook is organized in four sections for ready reference: general guidance on handbook content and use; a quick-look captain's summary; a more detailed review of general information on environmental conditions; and an appendix that provides oceanographic information.

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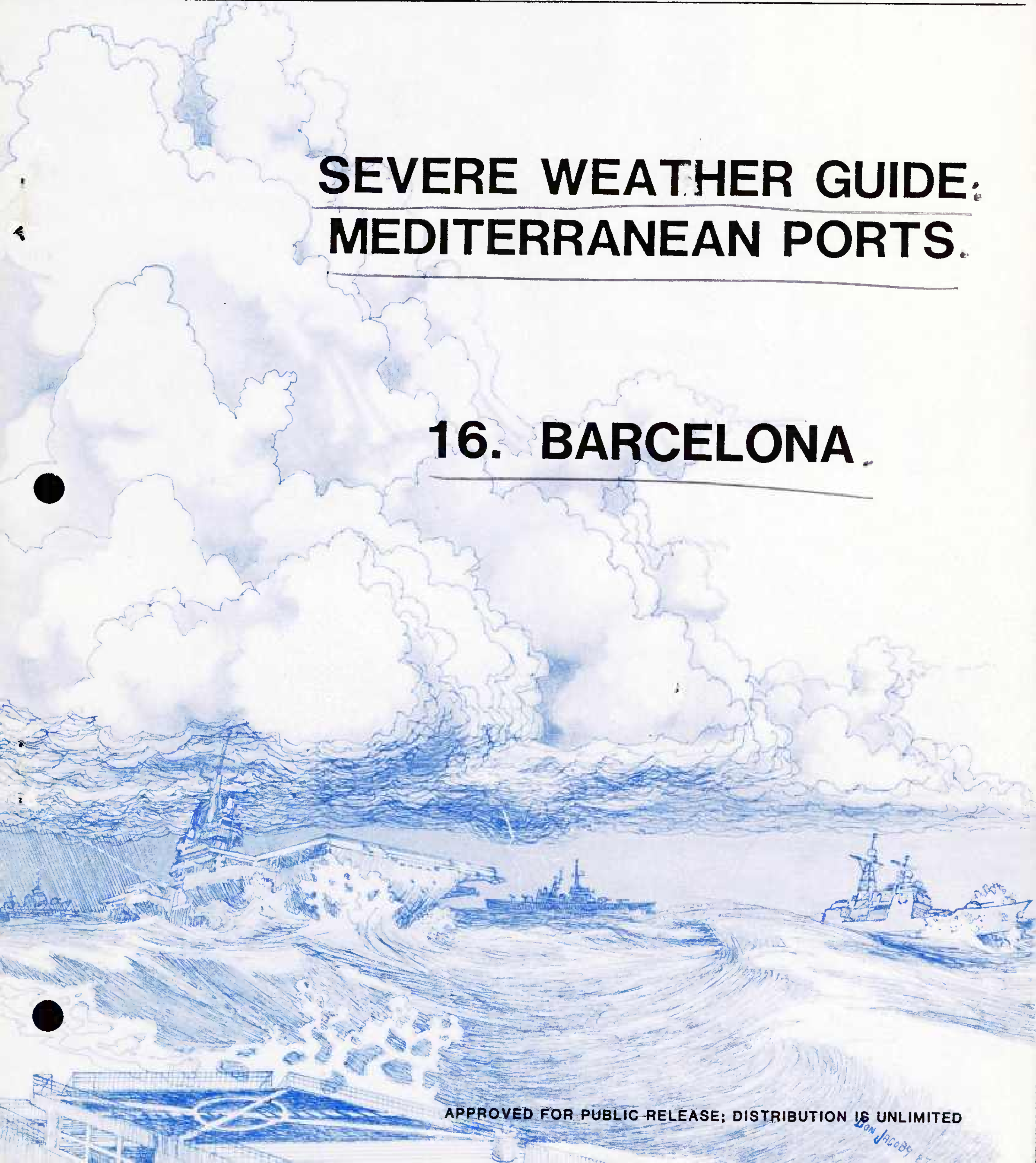
16. BARCELONA



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Enclosures (1)-(6) are, respectively, subject port studies volumes 16-Barcelona, 17-Palma, Mallorca, 18-Ibiza, 19-Pollensa Bay, 20-Livorno, and 21-La Spezia.

These studies document causes and effects of hazardous weather conditions for the Mediterranean ports specified. They provide decision-making guidance for ship captains, and contain information that will assist fleet meteorologists in making operational forecasts.

These port studies are more in a series expected ultimately to number more than 55 individual, port-specific severe weather guides to be produced by NAVENVPREDRSCHFAC over the next five years.

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CONTENTS

FOREWORD

This handbook on Mediterranean Ports was developed as part of an ongoing effort at the Naval Environmental Prediction Research Facility to create products for direct application to Fleet operations. The research was conducted in response to Commander Naval Oceanography Command (COMNAVOCEANCOM) requirements validated by the Chief of Naval Operations (OP-096).

As mentioned in the preface, the Mediterranean region is unique in that several areas exist where local winds can cause dangerous operating conditions. This handbook will provide the ship's captain with assistance in making decisions regarding the disposition of his ship when heavy winds and seas are encountered or forecast at various port locations.

Readers are urged to submit comments, suggestions for changes, deletions and/or additions to Naval Oceanography Command Center (NAVOCEANCOMCEN), Rota with a copy to the oceanographer, COMSIXTHFLT. They will then be passed on to the Naval Environmental Prediction Research Facility for review and incorporation as appropriate. This document will be a dynamic one, changing and improving as more and better information is obtained.

W. L. SHUTT
Commander, U.S. Navy

PORT INDEX

The following is a tentative prioritized list of Mediterranean Ports to be evaluated during the five-year period 1988-92, with ports grouped by expected year of the port study's publication. This list is subject to change as dictated by circumstances and periodic review.

1988 NO.	PORT
1	GAETA, ITALY
2	NAPLES, ITALY
3	CATANIA, ITALY
4	AUGUSTA BAY, ITALY
5	CAGLIARI, ITALY
6	LA MADDALENA, ITALY
7	MARSEILLE, FRANCE
8	TOULON, FRANCE
9	VILLEFRANCHE, FRANCE
10	MALAGA, SPAIN
11	NICE, FRANCE
12	CANNES, FRANCE
13	MONACO
14	ASHDOD, ISRAEL
15	HAIFA, ISRAEL
16	BARCELONA, SPAIN
17	PALMA, SPAIN
18	IBIZA, SPAIN
19	POLLENSA BAY, SPAIN
20	LIVORNO, ITALY
21	LA SPEZIA, ITALY
22	VENICE, ITALY
23	TRIESTE, ITALY
24	CARTAGENA, SPAIN
25	VALENCIA, SPAIN
	SAN REMO, ITALY
	GENOA, ITALY

1989	PORT
	SPLIT, YUGOSLAVIA
	DUBROVNIK, YUGOSLAVIA
	TARANTO, ITALY
	PALERMO, ITALY
	MESSINA, ITALY
	TAORMINA, ITALY
	PORTO TORRES, ITALY

1990	PORT
	BENIDORM, SPAIN
	ROTA, SPAIN
	TANGIER, MOROCCO
	PORT SAID, EGYPT
	ALEXANDRIA, EGYPT
	ALGIERS, ALGERIA
	TUNIS, TUNISIA
	GULF HAMMAMET, TUNISIA
	GULF OF GABES, TUNISIA
	SOUDA BAY, CRETE

1991	PORT
	PIRAEUS, GREECE
	KALAMATA, GREECE
	THESSALONIKI, GREECE
	CORFU, GREECE
	KITHIRA, GREECE
	VALETTA, MALTA
	LARNACA, CYPRUS

1992	PORT
	ANTALYA, TURKEY
	ISKENDERUN, TURKEY
	IZMIR, TURKEY
	ISTANBUL, TURKEY
	GOLCUK, TURKEY
	GULF OF SOLLUM

PREFACE

Environmental phenomena such as strong winds, high waves, restrictions to visibility and thunderstorms can be hazardous to critical Fleet operations. The cause and effect of several of these phenomena are unique to the Mediterranean region and some prior knowledge of their characteristics would be helpful to ship's captains. The intent of this publication is to provide guidance to the captains for assistance in decision making.

The Mediterranean Sea region is an area where complicated topographical features influence weather patterns. Katabatic winds will flow through restricted mountain gaps or valleys and, as a result of the venturi effect, strengthen to storm intensity in a short period of time. As these winds exit and flow over port regions and coastal areas, anchored ships with large 'sail areas' may be blown aground. Also, hazardous sea state conditions are created, posing a danger for small boats ferrying personnel to and from port. At the same time, adjacent areas may be relatively calm. A glance at current weather charts may not always reveal the causes for these local effects which vary drastically from point to point.

Because of the irregular coast line and numerous islands in the Mediterranean, swell can be refracted around such barriers and come from directions which vary greatly with the wind. Anchored ships may experience winds and seas from one direction and swell from a different direction. These conditions can be extremely hazardous for tendered vessels. Moderate to heavy swell may also propagate outward in advance of a storm resulting in uncomfortable and sometimes dangerous conditions, especially during tending, refueling and boating operations.

This handbook addresses the various weather conditions, their local cause and effect and suggests some evasive action to be taken if necessary. Most of the major ports in the Mediterranean will be covered in the handbook. A priority list, established by the Sixth Fleet, exists for the port studies conducted and this list will be followed as closely as possible in terms of scheduling publications.

RECORD OF CHANGES

CHANGE NUMBER	DATE OF CHANGE	DATE ENTERED	PAGE NUMBER	ENTERED BY

1. GENERAL GUIDANCE

1.1 DESIGN

This handbook is designed to provide ship captains with a ready reference on hazardous weather and wave conditions in selected Mediterranean harbors. Section 2, the captain's summary, is an abbreviated version of section 3, the general information section intended for staff planners and meteorologists. Once section 3 has been read, it is not necessary to read section 2.

1.1.1 Objectives

The basic objective is to provide ship captains with a concise reference of hazards to ship activities that are caused by environmental conditions in various Mediterranean harbors, and to offer suggestions for precautionary and/or evasive actions. A secondary objective is to provide adequate background information on such hazards so that operational forecasters, or other interested parties, can quickly gain the local knowledge that is necessary to ensure high quality forecasts.

1.1.2 Approach

Information on harbor conditions and hazards was accumulated in the following manner:

A. A literature search for reference material was performed.

B. Cruise reports were reviewed.

C. Navy personnel with current or previous area experience were interviewed.

D. A preliminary report was developed which included questions on various local conditions in specific harbors.

E. Port/harbor visits were made by NEPRF personnel; considerable information was obtained through interviews with local pilots, tug masters, etc; and local reference material was obtained.

F. The cumulative information was reviewed, combined, and condensed for harbor studies.

1.1.3 <u>Organization</u>

The Handbook contains two sections for each harbor. The first section summarizes harbor conditions and is intended for use as a quick reference by ship captains, navigators, inport/at sea OOD's, and other interested personnel. This section contains:

A. a brief narrative summary of environmental hazards,

B. a table display of vessel location/situation, potential environmental hazard, effect-precautionary/evasion actions, and advance indicators of potential environmental hazards,

C. local wind wave conditions, and

D. tables depicting the wave conditions resulting from propagation of deep water swell into the harbor.

The swell propagation information includes percent occurrence, average duration, and the period of maximum wave energy within height ranges of greater than 3.3 feet and greater than 6.6 feet. The details on the generation of sea and swell information are provided in Appendix A.

The second section contains additional details and background information on seasonal hazardous conditions. This section is directed to personnel who have a need for additional insights on environmental hazards and related weather events.

1.2. CONTENTS OF SPECIFIC HARBOR STUDIES

This handbook specifically addresses potential wind and wave related hazards to ships operating in various Mediterranean ports utilized by the U.S. Navy. It does not contain general purpose climatology and/or comprehensive forecast rules for weather conditions of a more benign nature.

The contents are intended for use in both pre-visit planning and in situ problem solving by either mariners or environmentalists. Potential hazards related to both weather and waves are addressed. The oceanographic information includes some rather unique information relating to deep water swell propagating into harbor shallow water areas.

Emphasis is placed on the hazards related to wind, wind waves, and the propagation of deep water swell into the harbor areas. Various vessel locations/situations are considered, including moored, nesting, anchored, arriving/departing, and small boat operations. The potential problems and suggested pre-cautionary/evasive actions for various combinations of environmental threats and vessel location/situation are provided. Local indicators of environmental hazards and possible evasion techniques are summarized for various scenarios.

CAUTIONARY NOTE: In September 1985 Hurricane Gloria raked the Norfolk, VA area while several US Navy ships were anchored on the muddy bottom of Chesapeake Bay. One important fact was revealed during this incident: Most all ships frigate size and larger dragged anchor, some more than others, in winds of over 50 knots. As winds and waves increased, ships 'fell into' the wave troughs, BROADSIDE TO THE WIND and become difficult or impossible to control.

This was a rare instance in which several ships of recent design were exposed to the same storm and much effort was put into the documentation of lessons learned. Chief among these was the suggestion to evade at sea rather than remain anchored at port whenever winds of such intensity were forecast.

2. CAPTAIN'S SUMMARY

The Port of Barcelona is located on the east coast of northeastern Spain (Figure 2-1), approximately 75 n mi south of the French border.

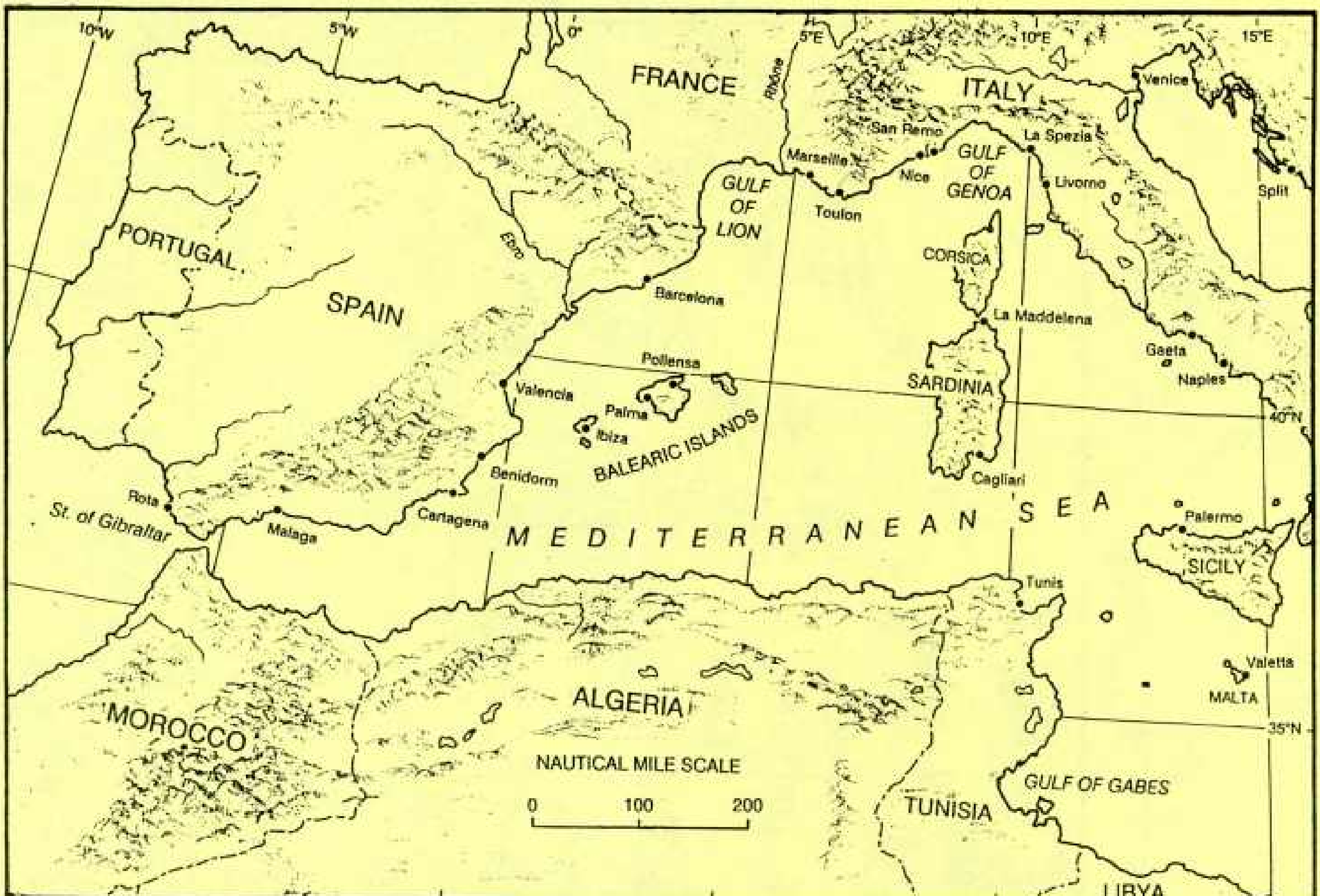

Figure 2-1. Western Mediterranean Sea.

Situated on the north coast of the Balearic Sea, the Port of Barcelona is positioned between the mouths of the Llobregat and Besos rivers at 41°22'N 002°11'E (Figure 2-2).

Figure 2-2. Region of the Port of Barcelona.

The Port of Barcelona is capable of accommodating several large ships (FICEURLANT, 1987). The facilities of the inner harbor are located in an artificial harbor bounded on the seaward side by a breakwater, Dique del Este, which is approximately 2 n mi long (Figure 2-3). The western half of the southern part of the port adjacent to the port entrance is protected by a second breakwater, Nuevo Contradique. Transverse moles divide the inner harbor into several basins. The aircraft carrier anchorage is situated about 0.6 to 0.8 n mi east of the green light at the south end of Dique del Este in a depth of 23 fm (42 m).

Two steel framework masts of an aerial tramway are located in the northern part of the harbor. The masts are prominent landmarks to approaching vessels. The tallest, 377 ft (115 m) high, stands on Muelle de Barcelona on the west side of the harbor. The second mast, 262 ft (80 m) high, stands on Muelle Nuevo on the east side. The two masts are connected by an overhead cable with a vertical clearance of approximately 200 ft (61 m) (FICEURLANT, 1987).

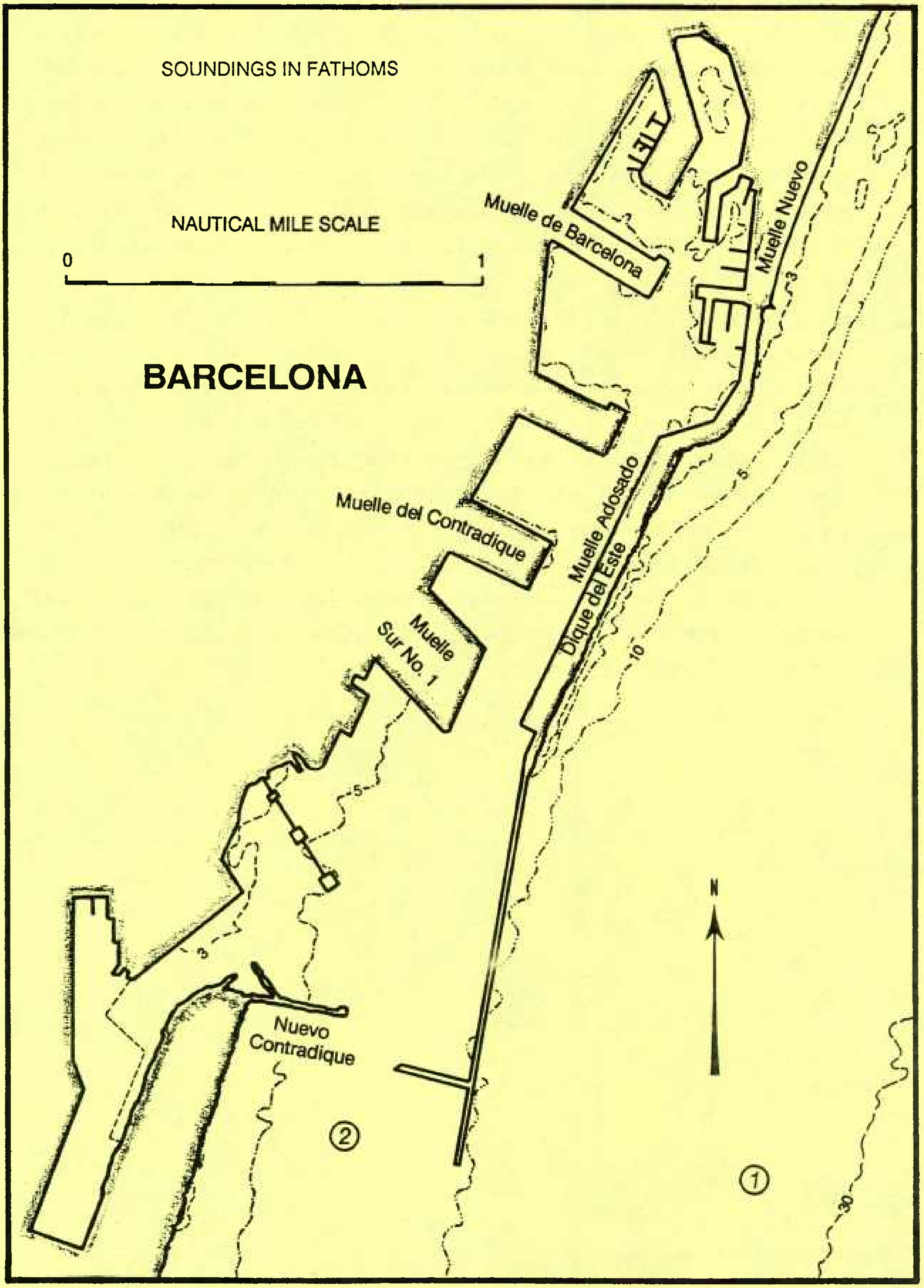

Figure 2-3. Port of Barcelona.

The inner harbor of the Port of Barcelona is generally well protected from most hazardous weather conditions, but southeasterly swell can refract through the south facing harbor entrance and cause difficulties for vessels moored at Muelle Sur No. 1. Also, according to FICEURLANT (1987), strong easterly winds can hamper maneuvering in the inner harbor. High winds with either an easterly or westerly direction can produce strong side forces on vessels moored north-south, with vessels having large sail areas being particularly vulnerable.

Muelle Adosado and Muelle del Contradique are located adjacent to deposits of sulfur and potash, and are, therefore, undesirable moorages on windy days.

The anchorage is exposed to wind and waves from northeast through southwest. The roadstead is sheltered only from offshore winds and is "a dangerous anchorage in winter" (FICEURLANT, 1987). Bottom type and holding qualities are not specified.

Currents are generally weak. Local authorities state that with no wind, the current has a 1/2 kt southerly set, but a persistent southerly wind can reverse the current direction. An onshore set of up to 1 kt is possible (Hydrographic Department, 1963).

There is little tidal change within the port. Diurnal barometric changes and the land/sea breeze regime can cause a water level variation of 1 ft (30 cm). Onshore winds can increase the water level by 3 ft (0.9m), while offshore winds can decrease it by 1 ft (30 cm)

Specific hazardous environmental conditions, vessel situations, and suggested precautionary/evasive action scenarios are summarized in Table 2-1.

Table 2-1. Summary of hazardous environmental conditions for the Port of Barcelona, Spain.

HAZARDOUS CONDITION	INDICATORS OF POTENTIAL HAZARD	VESSEL LOCATION/ SITUATION AFFECTED	EFFECT - PRECAUTIONARY/EVASIVE ACTIONS
1. Levante winds/waves - E'ly winds/waves that bring worst weather conditions to Barcelona. * Strongest occurrences usually caused by extratropical depressions over Balearic Islands. * May occur year-round but strongest in winter and early spring. * Commonly accompanied by clouds, rain, and occasional thundershowers.	Advance warning * A low NE swell can be observed 10-14 hr in advance of wind onset. NOTE: The swell can also be caused by Mistral winds over the Gulf of Lion. * A water level decrease of 1 ft (30 cm) portends bad weather in 12 to 24 hr, with the weather normally approaching from the east, but it may come from the northwest. NOTE: This guideline should be used with caution since a diurnal barometric tide must be taken into account. * If a NE swell is present at Barcelona in the afternoon, boating will be cancelled the next day, and for the following 3 days. Duration * May last 3-4 days after onset. * Associated inclement weather--cloudy skies, rain, and possible thundershowers--will persist as long as the wind, and usually 12-24 hr longer.	(1) Moored-inner harbor.	(a) Winds can create problems in inner harbor. * Wind may tend to force ships moored north-south off their berths. * Ships with large sail areas particularly vulnerable. * Tug assistance and/or additional mooring lines may be required. * Maneuvering may be made difficult in close confines of harbor. * Pilots will not move gas tankers in inner harbor once winds reach force 5 (17-21 kt). (b) Be aware of wind chill during winter.
		(2) Anchored in the roadstead.	(a) High winds/waves may force ships to leave the anchorage. * No nearby ports offer better protection. (b) Be aware of wind chill during winter.
		(3) Arriving/departing.	(a) Winds and/or waves cause problems in the inner harbor and in the roadstead. * Wind may make maneuvering difficult in close confines of inner harbor. Tug assistance may be required. * Pilots will not move gas tankers in inner harbor once winds reach force 5 (17-21) kt. * High winds/waves may force ships to weigh anchor and leave the roadstead. * No nearby ports offer better protection. (b) Be aware of wind chill during winter.
		(4) Small boats.	(a) Inner harbor operations should be largely unaffected. * Inner harbor is well protected by Dique del Este. * Runs to/from roadstead may be curtailed due to winds and waves creating dangerous conditions outside harbor entrance. * The wind can change directions quickly during winter, causing wind waves to cross the swell waves, creating a dangerous condition for small boats outside the harbor entrance. (b) Be aware of wind chill during winter.

Table 2-1. (Continued)

HAZARDOUS CONDITION	INDICATORS OF POTENTIAL HAZARD	VESSEL LOCATION/ SITUATION AFFECTED	EFFECT - PRECAUTIONARY/EVASIVE ACTIONS
2. Vendaval/Poniente winds - W'ly winds which precede/follow cold frontal passage. * Strong westerly winds are infrequent at Barcelona, but on extremely rare occasions may reach 60 kt. * Offshore component usually precludes significant wave generation at Barcelona, but if Vendaval winds are S to SW, waves may be raised in the roadstead. * Vendaval (pre-frontal) winds may be accompanied by rain. * Poniente (post-frontal) winds usually bring clearing conditions with possible scattered showers.	Advance warning * Vendaval winds usually precede a cold front approaching Barcelona, with Poniente winds following it. Strong winds in either situation are rare. * Poniente winds are potentially the strongest of the two, but lee trough reduces wind force along coast. Exceptionally strong push of high pressure behind front could result in winds to 60 kt at Barcelona. Duration * Once onset, Vendaval winds will usually last until time of frontal passage. * Poniente winds will normally be strongest soon after frontal passage and last only a few hours before diminishing.	(1) Moored-inner harbor.	(a) Strong event produces side forces on ships moored north-south. * Tug assistance and/or additional mooring lines may be required to keep vessels on moorings. * Ships with large sail areas particularly vulnerable. * Pilots will not move gas tankers in inner harbor once winds reach force 5 (17-21 kt). (b) Be aware of wind chill in winter.
		(2) Anchored in the roadstead.	(a) Strong event may require deployment of 2 anchors to prevent dragging. * Wind is major factor due to offshore component. Lack of fetch usually reduces wave generation, but if Vendaval direction is south to south-west, waves may be raised in the roadstead. (b) Be aware of wind chill during winter.
		(3) Arriving/departing.	(a) Strong event can cause maneuvering problems in inner harbor and anchor dragging in the roadstead. * Maneuvering problems are amplified by small confines of harbor. * Two anchors may be required to prevent anchor dragging. (b) Outbound units should be aware Poniente wind will likely increase about 50 n mi from coast as protection of lee trough is lost. (c) Be aware of wind chill during winter.
		(4) Small boats.	(a) Operations at the Port should be only minimally affected in all but a rare, strong event. * Lack of fetch precludes wave buildup in the inner harbor. * Runs to/from the roadstead may be affected by the chop raised by a strong event. * The wind can change directions quickly during winter, causing wind waves to cross the swell waves, creating a dangerous condition for small boats outside the harbor entrance. (b) Be aware of wind chill factor in winter.
3. SE'ly swell - Generated by synoptic scale SE'ly wind flow. * Swell waves pass through entrance to inner harbor. * Normally occurs 3-5 days per year.	Advance warning * May be expected anytime synoptic scale SE'ly flow exists over the Mediterranean Sea southeast of Barcelona, such as Scirocco conditions in warm sectors of cyclones passing north of Barcelona. Duration * Will diminish gradually after wind field over fetch area weakens or moves. With time, swell waves will diminish in height and have shorter periods.	(1) Moored-inner harbor.	(a) Swell waves refract through harbor entrance and impact ships moored at Muelle Sur No. 1. * Additional mooring lines may be required to prevent excessive motion of moored vessels.
		(2) Anchored in the roadstead.	(a) Not usually a problem for ships in the roadstead; leaving the anchorage should not be required. * If waves are unusually high and a sortie is indicated, moving to the anchorage at Pollensa Bay, Mallorca will afford better protection from SE'ly waves.
		(3) Arriving/departing.	(a) Waves should not pose significant problems to inbound/outbound units. * Waves may cause excessive motion at Muelle Sur No. 1. * If waves in roadstead are considered too high for anchoring, moving to the anchorage at Pollensa Bay, Mallorca will afford better protection from SE'ly waves.
		(4) Small boats.	(a) Waves alone should not significantly affect most operations. * Swell may refract through harbor entrance and impact Muelle Sur No. 1. Reflected waves may cause a chop in the south part of the harbor.

Table 2-1. (Continued)

HAZARDOUS CONDITION	INDICATORS OF POTENTIAL HAZARD	VESSEL LOCATION/ SITUATION AFFECTED	EFFECT - PRECAUTIONARY/EVASIVE ACTIONS
4. <u>Mistral induced NE'ly swell</u> - Waves propagate SW from wind field over the Gulf of Lion. * May reach 6 to 10 ft (2 to 3 m). * A 40 kt Mistral will cause a 4 ft swell at Barcelona.	<u>Advance warning</u> * Swell can be expected soon after a Mistral starts to blow over the Gulf of Lion. <u>Duration</u> * Highest waves usually last 2 to 3 hr after onset, but may last 6 to 12 hr. * Swell will persist as long as a Mistral is present over Gulf of Lion.	(1) <u>Anchored in the roadstead.</u>	(a) <u>The roadstead is exposed to the waves.</u> * If the swell reaches the 6-10 ft height possible during initial onset, remaining in the anchorage may not be prudent; Especially so if the local direction is more-or-less perpendicular to the swell direction so that the anchored vessels are subject to rolling. * If moving to a protected anchorage is desired the anchorages at Palma, Mallorca (best) and Ibiza, Ibiza should be considered.
		(2) <u>Arriving/departing.</u>	(a) <u>Unless the arrival of inbound units should coincide with swell in the 6-10 ft range, no significant problems should ensue.</u> * A wind which is perpendicular to the swell direction may cause anchored vessels to windcock and roll in the beam wave condition. * The alternate anchorages of Palma, Mallorca (best) and Ibiza, Ibiza should be considered if remaining at Barcelona is deemed inadvisable.
		(3) <u>Small boats.</u>	(a) <u>Small boat operation in the inner harbor should be unaffected except near Meulle Sur No. 1, where refracted/reflected waves may create a chop.</u> (b) <u>Runs to/from the roadstead may be affected.</u> * Swell alone should not pose a problem, but wind waves on top of the swell could create difficult boating conditions.
5. <u>Sea breeze</u> - Wind occurring on warm days. * Commonly reaches force 3-4 (7-10 to 11-16 kt), but strong event may attain force 5-6 (17-21 to 22-27 kt). * Direction veers as hillsides are warmed by the sun. * Starts mid to late morning as E'ly. * Veers to SW'ly by late afternoon. * Can raise a 3 ft (0.9 m) sea in the roadstead.	<u>Advance warning</u> * To be expected on warm days. * Common during all months except November, December, January, and February. <u>Duration</u> * Starts mid to late morning. * Dies soon after sunset.	(1) <u>Small boats.</u>	(a) <u>Runs to/from the roadstead may be affected by sea raised by the wind.</u> * Whenever possible, runs to/from the roadstead should be scheduled to avoid mid to late afternoon hours when wind force is highest.

For estimating shallow water wave heights, two points have been selected (Figure 2-3). Point 1 is in the anchorage area east of the harbor entrance while Point 2 is near the entrance to the harbor.

Table 2-2 provides the height ratio and direction of shallow water waves to expect at Points 1 and 2 when the deep water wave conditions are known.

The Barcelona Point 1 conditions are found by entering Table 2-2 with the forecast or known deep water wave direction and period. In the following example, the height is determined by multiplying the deep water height (8 ft) by the ratio of shallow to deep height (.9).

Example: Use of Table 2-2 for Barcelona Point 1.
Deep water wave forecast as provided by a forecast center or a reported/observed deep water wave condition: 8 feet, 10 seconds, from 150°. The expected wave condition at Barcelona Point 1, as determined from Table 2-2: 7 feet, 10 seconds, from 145°.

NOTE: Wave periods are a conservative property and, therefore, remain constant when waves move from deep to shallow water, but speed, height, and steepness change.

Table 2-2. Shallow water wave directions and relative height conditions versus deep water period and direction (see Figure 2-3 for location of the points).

FORMAT: Shallow Water Direction
Wave Height Ratio: (Shallow Water/Deep Water)

BARCELONA POINT 1: Carrier Anchorage Depth 138 ft

Period (sec)	6	8	10	12	14	16
Deep Water Direction	Shallow Water Direction and Height Ratio					
060°	060° 1.0	060 1.0	070° .9	075° .7	080° .6	085° .5
090°	090° 1.0	090° 1.0	090° .9	095° .8	105° .6	110° .4
120°	120° 1.0	120° 1.0	120° .9	120° .9	120° .9	120° .9
150°	150° 1.0	150° 1.0	145° .9	145° .8	140° .8	140° .8
180°	180° 1.0	175° .8	170° .8	170° .7	160° .6	155° .6
210°	205° .6	195° .7	180° .5	170° .4	170° .5	160° .5
240°	225° .6	210° .8	180° .4	190° .3	190° .3	190° .4

BARCELONA POINT 2: Harbor Entrance Depth 40 ft

Period (sec)	6	8	10	12	14	16
Deep Water Direction	Shallow Water Direction and Height Ratio					
060°	100° .3	105° .3	110° .4	110° .5	115° .6	115° .3
090°	100° .9	100° .9	115° .5	120° .6	100° .6	100° .5
120°	120° .8	115° .8	110° .9	110° 1.0	115° .9	110° 1.0
150°	140° .8	135° .7	135° .7	125° .8	125° .9	120° .9
180°	170° .9	145° .7	140° .4	130° .4	125° .6	125° .4
210°	170° .3	160° .2	150° .4	145° .4	135° .4	130° .5
240°	200° .3	190° .3	165° .3	150° .4	160° .4	165° .5

The local wind generated wave conditions for the anchorage area identified as Point 1 are given in Table 2-3. All heights refer to the significant wave height (average of the highest 1/3 waves). Enter the local wind speed and direction in this table to obtain the minimum duration in hours required to develop the indicated fetch limited sea height and period. The time to reach fetch limited height is based on an initial flat ocean. When starting from a pre-existing wave height, the time to fetch limited height will be shorter.

Table 2-3. Barcelona. Local wind waves for fetch limited conditions at Point 1 (based on JONSWAP model).

Point 1.

Format: height (feet)/period (seconds)
time (hours) to reach fetch limited height

Direction and Fetch Length (n mi) \ Local Wind Speed (kt)	18	24	30	36	42
SW 3 n mi	<2 ft	<2 ft	2/3 1	2/3 1	2-3/3 1
NE 15 n mi	2-3/4 2	3-4/4 2	4/4-5 2	5/5 2	6/5 2

Example:

To the northeast (045°) of Point 1 there is about a 15 n mi fetch (Figure 2-2). Given a northeast wind at 30 kt, the sea will have reached 4 feet with a period of 4-5 seconds within 2 hours. Wind waves will not grow beyond this condition unless the wind speed increases or the direction changes to one over a longer fetch length. If the wind waves are superimposed on deep water swell, the combined height may change in response to changing swell conditions. Wind wave directions are assumed to be the same as the wind direction.

Climatological factors of shallow water waves, as described by percent occurrence, average duration, and period of maximum energy (period at which the most energy is focused for a given height), are given in Table 2-4. See Appendix A for discussion of wave spectrum and energy distribution. These data are provided by season for two Rranges of heights: greater than 3.3 ft (1 m) and greater than 6.6 ft (2 m).

Table 2-4. Shallow water climatology as determined from deep water wave propagation. Percent occurrence, average duration or persistence, and wave period of maximum energy for wave height ranges of greater than 3.3 ft (1 m) and greater than 6.6 ft (2 m) by climatological season.

BARCELONA POINT 1:	WINTER	SPRING	SUMMER	AUTUMN
>3.3 ft (1 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	13	7	3	13
Average Duration (hr)	14	11	10	13
Period Max Energy (sec)	8	9	8	8-9
>6.6 ft (2 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	4	1	0	2
Average Duration (hr)	10	8	NA	13
Period Max Energy (sec)	10	9	NA	10

BARCELONA POINT 2:	WINTER	SPRING	SUMMER	AUTUMN
>3.3 ft (1 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	10	5	1	10
Average Duration (hr)	12	10	8	14
Period Max Energy (sec)	9	9	8-9	9
>6.6 ft (2 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	1	< 1	0	< 1
Average Duration (hr)	12	12	NA	12
Period Max Energy (sec)	11	10	NA	11

SEASONAL SUMMARY OF BARCELONA HAZARDOUS WEATHER CONDITIONS

WINTER (mid-January thru March):

* Levante: easterly 34 to 40 kt, high seas, rain and thunderstorms for 3 or 4 days.
* Mistral: high winds do not approach within 60 n mi, but 6 to 10 ft (2 to 3 m) swell reaches roadstead; may last up to 12 hours.
* Poniente: westerly wind following frontal passage; rare cases to 60 kt. Typically gale force outside 50 n mi offshore.
* Wind chill: may reach -20° to -40°F on windy days following cold front passage.
* Visibility: normally restricted to 3 to 4 n mi.

SPRING (April to mid-June):

* Levante: maximum frequency March and April.
* Mistral: common during April, 6 to 10 ft (2 to 3 m) swell reaches roadstead normally for 2 to 3 hours but can last up to 12 hours. 40 kt Mistral in Gulf of Lion results in 4 ft swell in roadstead.
* Visibility: poor, near zero; occurs a couple of times each spring. Normally 3 to 4 n mi.
* Sea breeze: increases during season to maximum of 17 to 27 kt; up to 3 ft wind waves. Direction follows the sun, ends abruptly after sunset.

SUMMER (mid-June thru September):

* Daily sea breeze: commonly 7 to 16 kt, maximum of 17 to 27 kt, direction follows the sun, waves up to 3 ft, end shortly after sunset.
* Visibility: normally 3 to 4 n mi.

AUTUMN (October thru mid-January):

* Levante and Poniente of winter begin to occur with increasing frequency and strength.
* Visibility best of year, occasionally improving beyond normal 3 to 4 n mi.

NOTE: For more detailed information on hazardous weather conditions see previous Summary Table in this section and Hazardous Weather Summary in Section 3.

REFERENCES

FICEURLANT, 1987: Port Directory for Barcelona (1985), Spain. Fleet Intelligence Center Europe and Atlantic, Norfolk, Virginia.

Hydrographic Department, 1963: Mediterranean Pilot, Volume I. Published by the Hydrographic Department, under the authority of the Lords Commissioners of the Admiralty, London.

3. GENERAL INFORMATION

This section is intended for Fleet meteorologists/oceanographers and staff planners. Paragraph 3.5 provides a general discussion of hazards and Table 3-5 provides a summary of vessel locations/situations, potential hazards, effects-precautionary/evasive actions, and advance indicators and other information about the potential hazards by season.

3.1 Geographic Location

The Port of Barcelona is located on the east coast of northeastern Spain (Figure 3-1) in the Region of Catalonia, approximately 75 n mi south of the French border.

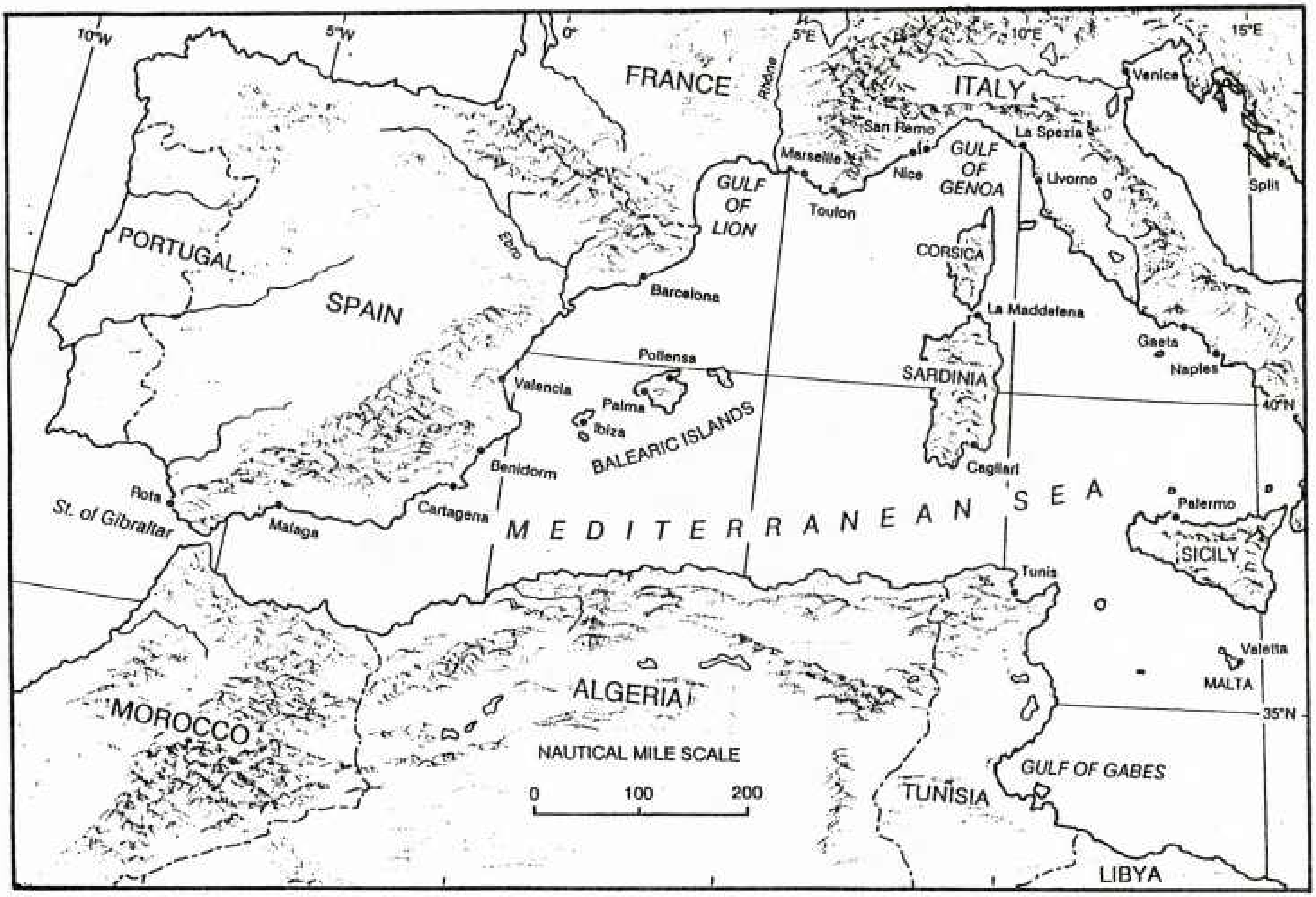

Figure 3-1. Western Mediterranean Sea.

Situated on the north coast of the Balearic Sea, the Port of Barcelona is positioned between the mouths of the Llobregat and Besos rivers at 41°22'N 002°11'E (Figure 3-2).

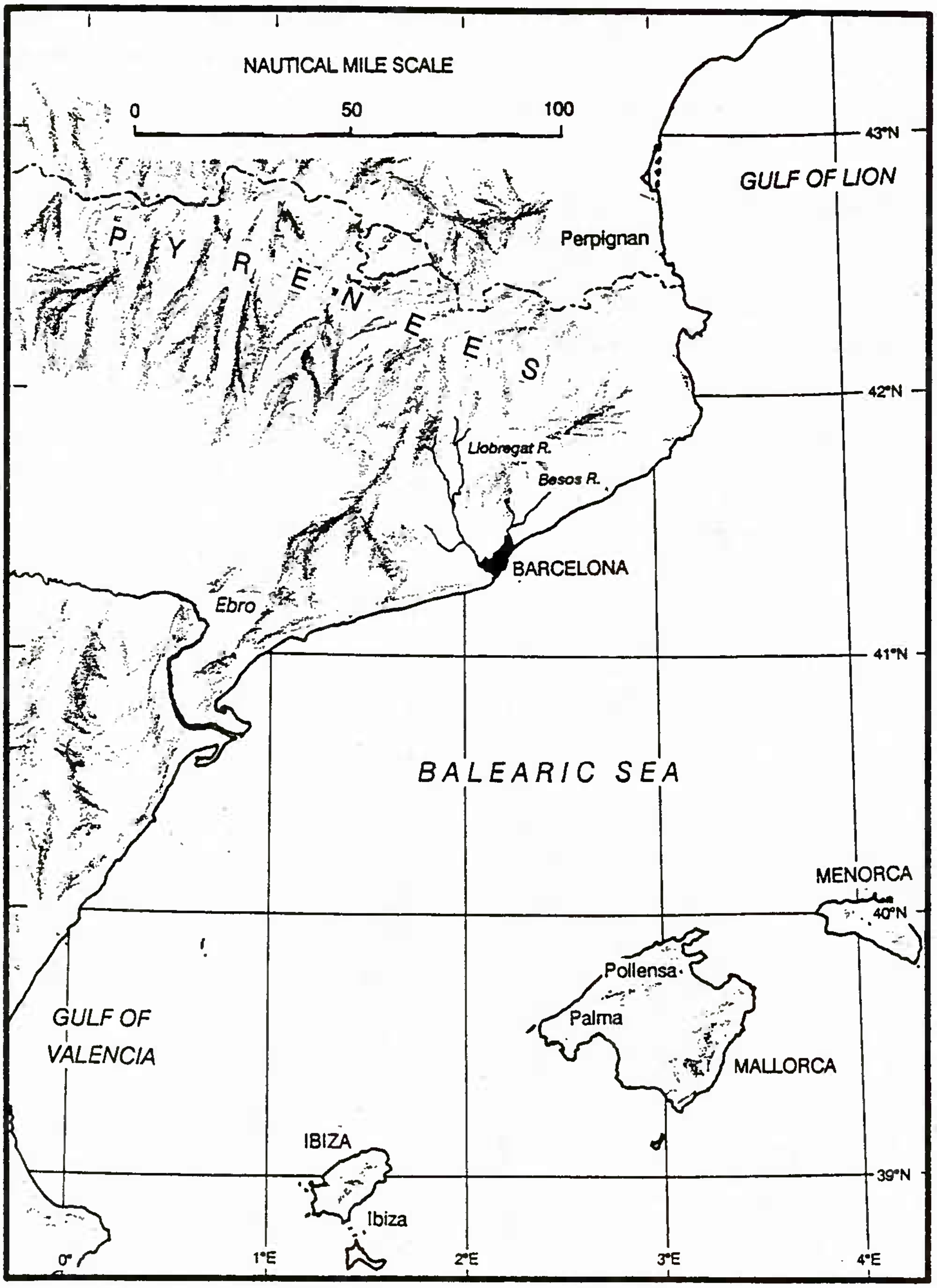

Figure 3-2. Region of the Port of Barcelona.

The Port of Barcelona is the largest Spanish port on the Mediterranean Sea, and is capable of accommodating several large ships (FICEURLANT, 1987). The facilities of the inner harbor are located in an artificial harbor bounded on the eastern, seaward side by a breakwater, Dique del Este, which is approximately 2 n mi long (Figure 3-3). The western half of the southern part of the port adjacent to the port entrance is protected by a second breakwater, Nuevo Contradique. Transverse moles divide the inner harbor into several basins. The aircraft carrier anchorage is situated about 0.6 to 0.8 n mi east of the green light at the south end of Dique del Este in a depth of 23 fm (42m). The bare, conical peaks of Montaña de Montserrat rise about 21 n mi northwest of the harbor, and provide an unmistakable landmark from seaward (Hydrographic Department, 1963). The highest peak in the group is Pico de San Jerómino, which has an elevation of 4,154 ft (1,266m).

Two steel framework masts of an aerial tramway are located in the northern part of the harbor. The masts are prominent landmarks to approaching vessels. The tallest, 377 ft (115 m) high, stands on Muelle de Barcelona on the west side of the harbor. The second mast, 262 ft (80 m) high, stands on Muelle Nuevo on the east side. The two masts are connected by an overhead cable with a vertical clearance of approximately 200 ft (61 m) (FICEURLANT, 1987).

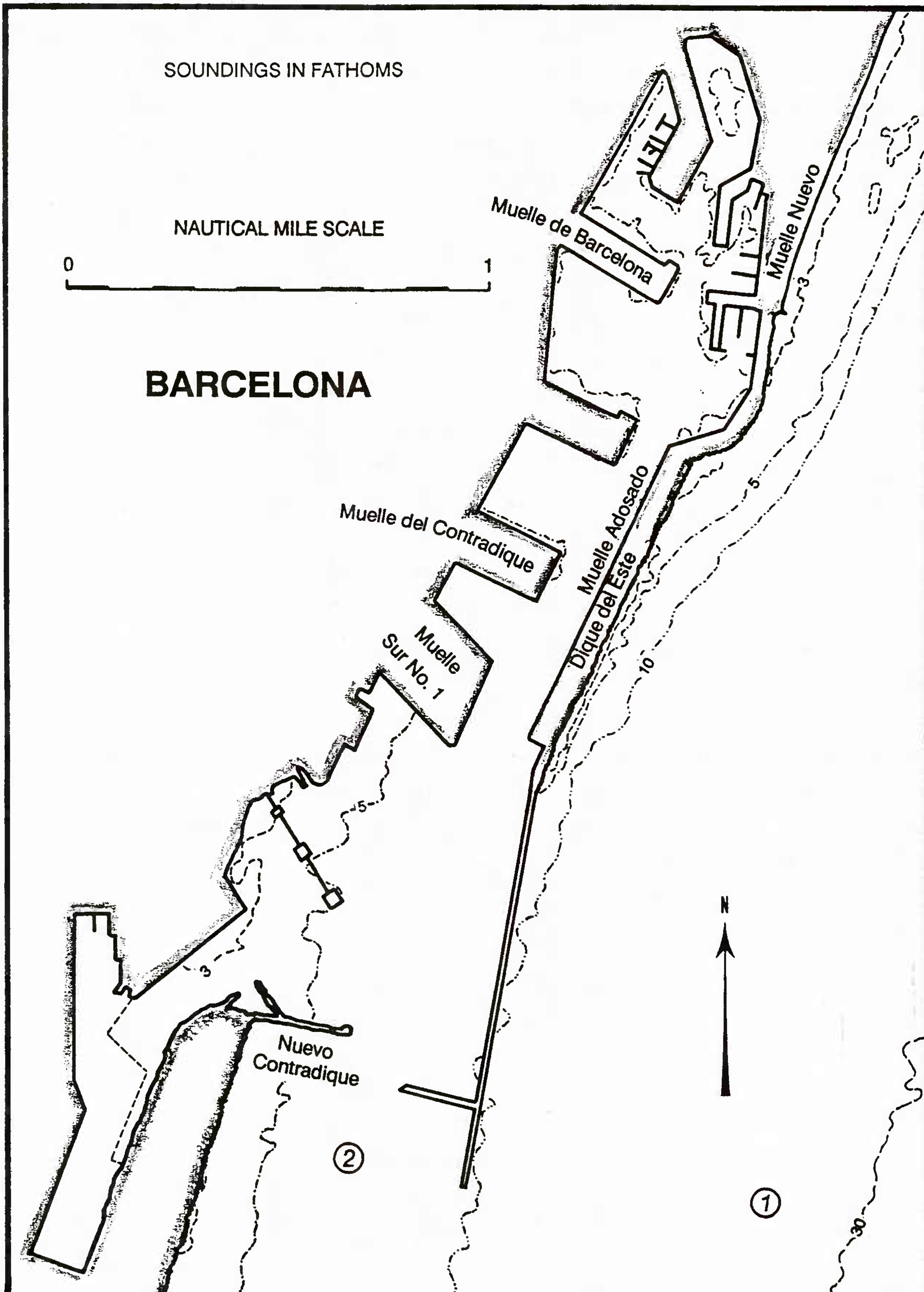

Figure 3-3. Port of Barcelona.

3.2 Qualitative Evaluation of the Port of Barcelona as a Haven

Barcelona is located between two areas which are subject to strong winds. It lies south of the area experiencing Mistral winds, the Gulf of Lion, and north of the strong westerly winds which blow over Tarragona. The result of this unique location is that Barcelona only infrequently experiences strong winds. According to Biel (1946), winds of force 7 (28-33 kt) only occur an average of 5.6 days per year at Barcelona. The greatest frequency of occurrence in January through April, with each of the months averaging 0.8 days with force 7 or higher winds.

The inner harbor of the Port of Barcelona is generally well protected from most hazardous weather conditions. According to the FICEURLANT (1987), wind and sea are no factors in the inner harbor, except strong easterly winds would hamper maneuvering. Local authorities indicate that ships moored at Muelle Sur No. 1 are exposed to south to southeasterly winds and waves, however. A southeasterly swell only occurs three to five days per year, usually due to synoptic scale southerly flow. Strong (near 60 kt) westerly winds have occurred only twice in a 14-year period, and caused problems for ships moored with a north-south orientation. As would be expected, vessels with a large sail area were most affected.

Muelle Adosado is located adjacent to a sulfur deposit, and Muelle del Contradique has a potash deposit on its north side. Consequently, both facilities are undesirable on windy days and should be avoided as mooring sites.

Large ships, such as aircraft carriers, use the anchorage located 0.6 to 0.8 n mi east of the south end of Dique del Este. The roadstead is sheltered only from offshore winds and is "a dangerous anchorage in winter", (FICEURLANT, 1987). The wind can change its direction suddenly during winter, causing wind waves to cross the

swell waves, creating a dangerous condition for small boats (Hydrographic Department, 1963). Mistral winds, known locally as Tramontana, have little or no effect on the inner harbor, but generate swell waves in the Gulf of Lion which are propagated to the anchorage. Swell height at onset may reach 6 to 10 ft (2 to 3 m) and usually lasts 2 to 3 hours but may last as long as 6 to 12 hours. A swell will be experienced in the roadstead as long as a Mistral is present over the Gulf of Lion, with a 40 kt wind producing a 4 ft swell at Barcelona.

3.3 Currents and Tides

Currents are generally weak. Local authorities state that with no wind, the current normally has a 1/2 kt southerly set, but a persistent southerly wind can reverse the current direction. An onshore set of up to 1 kt is possible (Hydrographic Department, 1963). Strong southeast winds cause variable currents in the harbor entrance (FICEURLANT, 1987).

There is little tidal change within the port. Diurnal barometric changes and a land/sea breeze regime can cause a water level variation of 1 ft (30 cm). Onshore winds can increase the water level by 3 ft (0.9 m), while offshore winds can decrease it by 1 ft (30 cm).

3.4 Visibility

Visibility at the Port of Barcelona is normally 3 to 4 n mi due to haze and industrial pollution. Fog reduces visibility to zero on an average of two days per year, with maximum frequency of occurrence in April. The best visibility conditions are usually observed during the autumn months.

3.5 Hazardous Conditions

The Port of Barcelona is well protected from winds and waves from southwest clockwise to northeast by the land mass of the Iberian Peninsula. The inner harbor is also well protected on its east side by the long breakwater which defines its eastern boundary. Consequently, the southern end of the inner harbor near the south-facing harbor entrance and the roadstead east of the inner harbor are the only areas of the port which experience much in the way of hazardous weather. A seasonal summary of the various known environmental hazards that may be encountered in the Port of Barcelona follows.

A. Winter (mid-January through March)

Although Barcelona is located in an area of normally light winds, some windy periods may be experienced all winter long at Barcelona. March and April are the windiest months of the season. Because of the configuration of the coastline of eastern Spain, winds with an easterly component have the potential to create the worst problems at Barcelona. Such winds are called "Levante", and may be caused by any one of several circumstances. Four types of Levante are identified in Weather in the Mediterranean, Volume I (Meteorological Office, Air Ministry, 1962): (1) mild Levante, associated with an extension of the Azores anticyclone over Spain (in winter) or southern France; (2) pre-frontal Levante, which precedes the arrival of a cold front from the Atlantic; (3) widespread Levante, associated with high pressure over western Europe and relatively lower pressure over the western Mediterranean; and (4) depression Levante, associated with a depression south of the Balearic Islands.

The strongest Levante winds are most often associated with Depression Levantes. The depressions may result from cyclogenesis over the Balearic Islands, or form elsewhere and move into the area. Winter Levante

conditions are most common in February and March, and may bring high winds and waves for three or four days. Overcast skies, rain, and thundershowers commonly accompany Levante conditions, persisting as long as the wind and waves, and even as much as 12 to 24 hours longer (Shaver, undated). The major impact of Levante winds and resultant waves on the Port of Barcelona is at the roadstead, where conditions may deteriorate to the point where vessels may be forced to weigh anchor and seek better protected waters.

The most widely known wind event in the western Mediterranean Sea, the Mistral (known locally as Tramontana, Cers or Cierzo), poses only minor problems to the port. The southern extent of the strong Mistral winds is commonly a line about 60 n mi northeast of Barcelona between Perpignan, France and Mahón, Menorca. Consequently, Mistral winds do not reach the port, but swell waves of 6 to 10 ft (2 to 3 m) propagate southwestward and reach the Barcelona roadstead. Ships anchored in the roadstead should be able to remain, as the highest waves usually last only for 2 to 3 hours after onset, although they may persist for 6 to 12 hours. A swell will be present in the roadstead as long as a Mistral is blowing over the Gulf of Lion. A 40 kt wind will result in a 4 ft swell at Barcelona. The strongest Mistral events occur late in the winter season.

Westerly winds known locally as Vendaval and Poniente occur at Barcelona, but strong events are rare. As mentioned in section 3.2, westerly winds near 60 kt have been experienced only twice in 14 years. Climatology records summarized in a Climatic Table for Barcelona airport in Mediterranean Pilot, (Hydrographic Department, 1963) show no events of wind from any direction greater than force 8 (34-40 kt) during an 8-year period of record. Vendaval winds are south-westerlies which precede cold fronts, while Poniente winds are the northwesterlies which are associated with building high pressure following cold frontal passage. Poniente winds are generally stronger than the Vendaval

in most areas, but the mountains along the eastern coast of Spain cause a lee trough to develop from Barcelona to Valencia during Poniente situations, resulting in light west to southwesterly winds out to 50 n mi offshore, with gale force northwesterlies occurring seaward (Brody and Nestor, 1980). Because of their offshore component and the lee trough effect, Poniente winds normally cause no important problems at Barcelona. Vendaval winds do not significantly impact the inner harbor, but can create a short-lived wave problem for ships in the roadstead if they have a south to southwest direction.

Swell from the southeast can enter the inner harbor and impact ships moored at Muelle Sur No. 1. Wind regimes which generate the southeasterly waves are normally synoptic scale events. One such producer of southeasterly winds over the western Mediterranean Sea is the Scirocco, a warm, sometimes hot, wind which originates over the deserts of North Africa. It usually occurs in the warm sectors of cyclones located north of the area. Scirocco winds are often accompanied by low stratus and fog near the Iberian Peninsula. Scirocco winds are called "Leveche" in southeastern Spain.

Precipitation increases during the season, reaching a maximum for the season during March.

January is the coldest month of the year, with a mean daily maximum temperature of 55°F (13°C) and a mean daily minimum of 42°F (6°C). The extreme low temperature recorded is 20°F (-7°C) (Hydrographic Department, 1963). While not a concern on most days at Barcelona, wind chill--the cooling effect of temperature combined with wind--is a factor to be considered on cool, windy days during winter for personnel working in exposed locations. Table 3-1 can be used to determine wind chill for various temperature and wind combinations.

Table 3-1. Wind Chill. The cooling power of the wind expressed as "Equivalent Chill Temperature" (adapted from Kotsch, 1983).

Wind Speed		Cooling Power of Wind expressed as "Equivalent Chill Temperature"								
Knots	MPH	Temperature (°F)								
Calm	Calm	40	35	30	25	20	15	10	5	0
		Equivalent Chill Temperature								
3-6	5	35	30	25	20	15	10	5	0	-5
7-10	10	30	20	15	10	5	0	-10	-15	-20
11-15	15	25	15	10	0	-5	-10	-20	-25	-30
16-19	20	20	10	5	0	-10	-15	-25	-30	-35
20-23	25	15	10	0	-5	-15	-20	-30	-35	-45
24-28	30	10	5	0	-10	-20	-25	-30	-40	-50
29-32	35	10	5	-5	-10	-20	-30	-35	-40	-50
33-36	40	10	0	-5	-15	-20	-30	-35	-45	-55

B. Spring (April to mid-June)

The winter weather events described above continue through April, but diminish in frequency and intensity as summer approaches. March and April are the windiest months of the year at Barcelona. Levante winds may occur throughout the season, but are usually associated with cyclonic activity over the Balearic Sea early in the season. By late spring they are relatively weak as they are caused by broad scale flow between the Azores anticyclone extending over the Iberian Peninsula and lower pressure over North Africa.

Like the Levante, Vendaval and Poniente winds occur with decreasing frequency and intensity after April, with strong events being rare. Mistral conditions are common over the Gulf of Lion early in the season, and the resultant swell propagates southwestward to Barcelona. Swell waves of 6 to 10 ft (2 to 3 m) may reach the roadstead, commonly lasting for only 2 to 3 hours but sometimes lasting for 6 to 12 hours. As long as Mistral winds are present over the Gulf of Lion, a swell will persist in the Barcelona roadstead, with a 40 kt wind resulting in a 4 ft swell. Scirocco winds and other synoptic scale events are possible throughout the season, generating a southeasterly swell which may

propagate to Barcelona, causing difficulty for ships moored to Muelle Sur No. 1.

Although amounts are less than those recorded during the September through November period, the spring season brings significant precipitation to the Barcelona area. According to Biel (1946), precipitation occurs on an average of 8 days during April, 7 in May, and 5 days during the entire month of June.

Spring is the season experiencing the poorest visibility at the Port of Barcelona. The two days per year (approximate) during which the near zero visibility reductions occur are most likely during April.

Temperatures warm considerably during the season, with the mean daily maximum temperature reaching 78°F (26°C) during June. The warm days initiate a daily sea/land breeze regime. The sea breeze is normally in the force 3 to 4 (7-16 kt) range but may reach force 5 to 6 (17-27 kt) under some conditions. The direction of the sea breeze "follows the sun" as hillsides are warmed, beginning as easterly in late morning, gradually veering to southwesterly by late afternoon. The sea breeze ends shortly after sunset. Seas to 3 ft (0.9 m) in the roadstead are routine during the afternoon.

C. <u>Summer (mid-June through September)</u>

Barcelona's summer weather is pleasant, with light winds, warm days, and cool nights being the rule. Strong winds are possible, but their impact and frequency of occurrence would be much less than that experienced during late winter and early spring.

Daily sea breezes occur on 80 to 90 percent of all summer days (Biel, 1946). They commonly reach force 3 to 4 (7-16 kt) during late afternoon, with a strong event attaining force 5 to 6 (17-27 kt). The direction of the breeze, which dies soon after sunset, is influenced by the warming of the hillsides by the sun, starting as easterly in late morning and veering to southwesterly by late afternoon. Seas of 3 ft (0.9 m) may be raised in the roadstead.

Summer is the dry season at Barcelona, with precipitation being recorded on an average of 3 days during July, the driest month (Biel, 1946).

D. Autumn (October to mid-January)

The transition season of autumn brings what some refer to as the "best" weather to Barcelona, although the term "best" is not defined. The wind events of winter--Levante, Poniente, and Vendaval--begin to occur with greater regularity as the extratropical storm track moves southward to its wintertime position over the northern Mediterranean Sea. Precipitation amounts increase markedly in September, reaching a maximum for the year in October, when precipitation is recorded an average of 8 days (Biel, 1946).

Visibility during autumn is generally the best of the year, with visibility occasionally improving above the 3 to 4 n mi that prevails during the rest of the year at Barcelona.

Temperatures decrease markedly each month after September, but wind chill (see Table 3-1) should not be a factor until late December.

3.6 Harbor Protection

As discussed below, much of the inner harbor of the Port of Barcelona is protected from most weather related events, but the roadstead and the southern part of the inner harbor are exposed and vulnerable to specific wind and wave conditions.

3.6.1 Wind and Weather

The configuration of the coastline protects the Port of Barcelona from most wind and weather from west-southwest, clockwise to northeast. As discussed in Section 3.2, however, strong (near 60 kt), westerly winds are uncommon, but have occurred on two occasions during a 14-year period. In those instances, ships which were moored with a north-south orientation encountered

problems due to the wind forcing them on/off their berths. The problem was particularly acute for ships with a large sail area. Strong easterly winds would have the same effect but, although they are more common, they are usually less than gale (34-40 kt) force. In general, wind alone causes only minimal problems in the inner harbor. Ships in the roadstead would be subject to anchor dragging in any strong wind, regardless of direction.

Weather, per se, is not a significant problem at the port. Thunderstorms are rare, and usually occur during the winter-to-spring and summer-to-autumn transition periods. The month of September has the greatest number of thunderstorms for a single month, with an average of 3.6 storms out of a yearly average of 16.5 (Biel, 1946).

3.6.2 Waves

Because the port area is protected from most winds from west-southwest clockwise through northeast, it is also sheltered from significant wave action from those directions. It is, however, exposed to waves from other directions.

The inner harbor is adversely affected only by waves from the southeast. They refract through the south-facing harbor entrance and affect ships moored at Muelle Sur No. 1. Southeasterly swell reaches Barcelona about 3 to 5 days per year.

The roadstead is exposed to waves from northeast clockwise through southwest. Because of its vulnerability, use of the anchorage is not recommended in winter or if high waves are expected. Ships should weigh anchor and leave the anchorage in any high wave situation, whether existing or forecast.

Table 3-2 provides the shallow water wave conditions at the two designated points when deep water swell enters the harbor.

Example: Use of Table 3-2.

For a deep water wave condition of 8 feet, 10 seconds, from 150°, the approximate shallow water wave conditions are:

Point 1: 7 feet, 10 seconds, from 145°
Point 2: 5-6 feet, 10 seconds, from 135°

Table 3-2. Shallow water wave directions and relative height conditions versus deep water period and direction (see Figure 3-3 for location of the points).

FORMAT: Shallow Water Direction
Wave Height Ratio: (Shallow Water/Deep Water)

BARCELONA POINT 1: Carrier Anchorage Depth 138 ft

Period (sec)	6	8	10	12	14	16
Deep Water Direction	Shallow Water Direction and Height Ratio					
060°	060° 1.0	060° 1.0	070° .9	075° .7	080° .6	085° .5
090°	090° 1.0	090° 1.0	090° .9	095° .8	105° .6	110° .4
120°	120° 1.0	120° 1.0	120° .9	120° .9	120° .9	120° .9
150°	150° 1.0	150° 1.0	145° .9	145° .8	140° .8	140° .8
180°	180° 1.0	175° .8	170° .8	170° .7	160° .6	155° .6
210°	205° .6	195° .7	180° .5	170° .4	170° .5	160° .5
240°	225° .6	210° .8	180° .4	190° .3	190° .3	190° .4

See next page for Barcelona Point 2.

Table 3-2 cont.

BARCELONA POINT 2: Harbor Entrance Depth 40 ft

Period (sec)	6	8	10	12	14	16
Deep Water Direction	Shallow Water Direction and Height Ratio					
060°	100°	105°	110°	110°	115°	115°
	.3	.3	.4	.5	.6	.3
090°	100°	100°	115°	120°	100°	100°
	.9	.9	.5	.6	.6	.5
120°	120°	115°	110°	110°	115°	110°
	.8	.8	.9	1.0	.9	1.0
150°	140°	135°	135°	125°	125°	120°
	.8	.7	.7	.8	.9	.9
180°	170°	145°	140°	130°	125°	125°
	.9	.7	.4	.4	.6	.4
210°	170°	160°	150°	145°	135°	130°
	.3	.2	.4	.4	.4	.5
240°	200°	190°	165°	150°	160°	165°
	.3	.3	.3	.4	.4	.5

Situation-specific shallow water wave conditions resulting from deep water wave propagation are given in Table 3-2, while the seasonal climatology of wave conditions in the harbor resulting from the propagation of deep water waves into the harbor are given in Table 3-3. If the actual or forecast deep water wave conditions are known, the expected conditions at the two specified harbor areas can be determined from Table 3-2. The mean duration of the condition, based on the shallow water wave heights, can be obtained from Table 3-3.

Example: Use of Tables 3-2 and 3-3.

The forecast for wave conditions tomorrow (winter case) outside the harbor are:
8 feet, 12 seconds, from 090°

Expected shallow water conditions and duration:

	Point 1	Point 2
Height	6 feet	5 feet
Period	12 seconds	12 seconds
Direction	from 095°	from 120°
Duration	14 hours	12 hours

Interpretation of the information from Tables 3-2 and 3-3 provides guidance on the local wave conditions expected tomorrow at the various harbor points. The duration values are mean values for the specified height range and season. Knowledge of the current synoptic pattern and forecast/expected duration should be used when available.

Possible applications to small boat operations are selection of the mother ships anchorage point, and/or areas of small boat work. The condition duration information provides insight as to how long before a change can be expected. The local wave direction information can be of use in selecting anchorage configuration and related small boat operations, including tending activities.

Table 3-3. Shallow water climatology as determined from deep water wave propagation. Percent occurrence, average duration or persistence, and wave period of maximum energy for wave height ranges of greater than 3.3 ft (1 m) and greater than 6.6 ft (2 m) by climatological season.

BARCELONA POINT 1:	WINTER	SPRING	SUMMER	AUTUMN
>3.3 ft (1 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	13	7	3	13
Average Duration (hr)	14	11	10	13
Period Max Energy (sec)	8	9	8	8-9
>6.6 ft (2 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	4	1	0	2
Average Duration (hr)	10	8	NA	13
Period Max Energy (sec)	10	9	NA	10
BARCELONA POINT 2:	WINTER	SPRING	SUMMER	AUTUMN
>3.3 ft (1 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	10	5	1	10
Average Duration (hr)	12	10	8	14
Period Max Energy (sec)	9	9	8-9	9
>6.6 ft (2 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	1	< 1	0	< 1
Average Duration (hr)	12	12	NA	12
Period Max Energy (sec)	11	10	NA	11

Local wind wave conditions are provided in Table 3-4 for Barcelona Point 1. The fetch lengths are specifically for Point 1. The time to reach the fetch limited height assumes an initial flat ocean. With a pre-existing wave height, the times are shorter.

Table 3-4. Barcelona. Local wind waves for fetch limited conditions at Point 1 (based on JONSWAP model).

Point 1.

Format: height (feet)/period (seconds)
time (hours) to reach fetch limited height

Direction and Fetch Length (n mi) \ Local Wind Speed (kt)	18	24	30	36	42
SW 3 n mi	<2 ft	<2 ft	2/3 1	2/3 1	2-3/3 1
NE 15 n mi	2-3/4 2	3-4/4 2	4/4-5 2	5/5 2	6/5 2

Example: Small boat wave forecasts for Point 2 (based on the assumption that swell is not a limiting condition).

Forecast for Tomorrow:

Time	Wind (Forecast)	Waves (Table 3-4)
prior to 1000 LST	NE 8-12 kt	< 2 ft
1000 to 1400	NE 12-18 kt	2-3 ft at 4 sec by 1400
1400 to 1900	NE 18-24 kt	building to 3-4 ft at 4 sec by 1600

Interpretation: Assuming that the limiting factor is waves greater than 3 feet, small boat operations will become marginal by 1400 and restricted by 1600.

Combined wave heights are computed by finding the square root of the sum of the squares of the wind wave and swell heights. For example, if the wind waves were 3 ft and the swell 8 ft the combined height would be about 8.5 ft.

$$\sqrt{3^2 + 8^2} = \sqrt{9 + 64} = \sqrt{73} \approx 8.5$$

Note that the increased height is relatively small. Even if the two wave types were of equal height the combined heights are only 1.4 times the equal height. In cases where one or the other heights are twice that of the other, the combined height will only increase over the larger of the two by 1.12 times (10 ft swell and 5 ft wind wave combined results in 11.2 ft height).

3.6.3 Wave Data Uses and Considerations

Local wind waves build up quite rapidly and also decrease rapidly when winds subside. The period and, therefore, length of wind waves is generally short relative to the period and length of waves propagated into the harbor (see Appendix A). The shorter period and length result in wind waves being characterized by choppy conditions. When wind waves are superimposed on deep water waves propagated into shallow water, the waves can become quite complex and confused. Under such conditions, when more than one source of waves is influencing a location, tending or joint operations can be hazardous even if the individual wave train heights are not significantly high. Vessels of various lengths may respond with different motions to the diverse wave lengths present. The information on wave periods, provided in the previous tables, should be considered when forecasts are made for joint operations of various length vessels.

3.7 Protective and Mitigating Measures

3.7.1 Sortie/Remain in Port

Due to the good protection provided by the breakwaters, ships moored in the inner harbor should not find it necessary to sortie under most conditions. Doubling of lines may be necessary to prevent vessels from shifting at their moorings in strong winds. Ships moored to Muelle Sur No. 1 may need to take similar action to reduce motion and chafing when a southeasterly swell enters the harbor.

If ships are moored north-south and strong easterly or westerly winds are forecast, ships should consider moving to a more favorable berth in the harbor or evading at sea until conditions abate. The foregoing is especially true for vessels with large sail areas. The harbor at Palma, Mallorca, in the Balearic Islands would afford better protection.

3.7.2 Moving to New Anchorage

The Barcelona Roadstead is not considered safe in winter (FICEURLANT, 1987). In the words of the Mediterranean Pilot, Volume I (Hydrographic Department, 1963): "The roadstead off Barcelona is bad, especially in winter...." Also, according to the same document, the wind can change direction very suddenly, causing wind waves to cross the swell waves, thereby creating a dangerous condition for small boats. Because of the vulnerability of the roadstead, ships should consider moving to a more protected anchorage if strong winds and/or high waves are forecast. The roadstead at Palma, Mallorca, in the Balearic Islands would offer better protection from winds and waves from northeast and east, but like Barcelona, Palma is vulnerable to conditions from the southern quadrant.

3.7.3 Scheduling

The sea breeze is a more or less daily occurrence at Barcelona during all but the coldest months. Because of restricted maneuvering room in the inner harbor, arrivals, departures, and berth changes should be scheduled for morning hours. Since visibility is usually at its worst just after sunrise, and the sea breeze does not reach its full strength until after noon, a mid to late morning evolution should be planned.

Harbor pilots are instructed to not bring gas tankers into the harbor when winds are force 5 (17-21 kt) or greater because of the difficult maneuvering problems induced by the large sail area of the ships. Similar cautions should be observed for ships of other hull types that have large sail areas.

3.8 Local Indicators of Hazardous Weather Conditions

Levante winds

Extratropical depressions, especially those which form over the Balearic Islands, sometimes move slowly and cause high winds and waves along the east coast of Spain, including the carrier anchorage at Barcelona. They may last for 3 or 4 days, or longer. A low northeasterly swell can be observed as much as 10 to 14 hours in advance of the onset (Brody and Nestor, 1980 and Shaver, undated). (NOTE: The swell may also be caused by a Mistral. See Mistral guidelines.) Overcast skies with multiple cloud layers, rain, and thundershowers will persist as long as the wind and waves do, and may last even 12 to 24 hours longer (Shaver, undated).

Onshore winds may increase the water level at Barcelona by 3 ft (0.9 m), while offshore winds may decrease it by 1 ft (30 cm) (FICEURLANT, 1987). Bad weather is indicated within 12 to 24 hours when the water level in the harbor lowers about 1 ft (30 cm). The weather will normally approach from the east but at times will come from the northwest. Good weather prevails when

the water level remains high. NOTE: This guideline should be used with caution since a diurnal barometric tide must also be taken into account.

It is a rule of thumb at Barcelona that anytime there is a northeasterly swell in Barcelona in the afternoon, boating will be cancelled for at least the next four days (Shaver, undated, and Brody and Nestor, 1980). NOTE: See Mistral guidelines.

Vendaval/Poniente winds

When a storm crosses the Iberian Peninsula, the wind at Barcelona shifts from easterly clockwise to northwesterly as the storm passes.

Mistral swell waves

Local authorities state that Mistral winds over the Gulf of Lion generate swell waves which reach the Barcelona roadstead as northeasterly 6 to 10 ft (2 to 3 m). The highest waves usually last 2 to 3 hr, but may persist for 6 to 12 hr. A northeasterly swell will be present at the carrier anchorage whenever a Mistral is present in the Gulf of Lion. A 40 kt Mistral will produce a swell of approximately 4 ft at Barcelona (Brody and Nestor, 1980).

General

Wind from the south generally indicates good weather.

The sea breeze direction follows the sun, changing directions as hillsides are warmed. It begins from the east in late morning, veering to southwest by late afternoon. It ends shortly after sunset. Sea breeze speeds are usually in the force 3 to 4 (7-16 kt) range, but can reach force 5 to 6 (17-27 kt). Seas of 3 ft (0.9 m) are raised in the anchorage by the sea breeze.

3.9 Summary of Problems, Actions, and Indicators

Table 3-5 is intended to provide easy-to-use seasonal references for meteorologists on ships using the Port of Barcelona. Table 2-1 (section 2) summarizes Table 3-5 and is intended primarily for use by ship captains.

Table 3-5. Potential problem situations at Port of Barcelona, Spain - ALL SEASONS

VESSEL LOCATION/SITUATION	POTENTIAL HAZARD	EFFECT - PRECAUTIONARY/EVASIVE ACTIONS	ADVANCE INDICATORS AND OTHER INFORMATION ABOUT POTENTIAL HAZARD
1. Moored - Inner harbor. Strongest in Winter & early Spring Summer Autumn	a. Levante Winds/waves - E'ly wind that brings the worst weather conditions to Barcelona. May result from one of several circumstances, but strongest conditions result from extratropical depressions over the Balearic Islands. May cause high winds (seldom exceed force 8 (34-40 kt)) and waves which last 3 or 4 days. Commonly accompanied by clouds, rain, and occasional thundershowers.	a. Wind may cause maneuvering problems for vessels in the inner harbor. Vessels moored with a north-south orientation may be forced on/off their berths. Line doubling may be required. Vessels with large sail areas are particularly susceptible. Pilots will not move gas tankers in inner harbor once wind reaches force 5 (17-21 kt). Be aware of wind chill during winter.	a. Extratropical depressions, including those that form over the Balearic Islands, sometimes move slowly and cause high winds and waves along the E coast of Spain for 3 or 4 days, sometimes longer. A low NE swell can be observed as much as 10 to 14 hr in advance of the onset. (NOTE: The NE swell can also be caused by a Mistral. See 2.d below.) Overcast skies with multiple cloud layers, rain, and thundershowers will persist as long as the wind and waves, and usually about 12 to 24 hr longer. Onshore winds may increase the water level at Barcelona by 3 ft (0.9 m), while offshore winds may decrease it by 1 ft (30 cm). Bad weather is indicated in 12 to 24 hr when the water level in the harbor lowers by 1 ft (30 cm). The weather will normally approach from the E, but at times will come from the NW. Good weather prevails when the water level remains high. NOTE: This guideline should be used with caution since a diurnal barometric tide must also be taken into account.
Most common in Winter & early Spring Autumn	b. Vendaval/Poniente winds - W'ly wind events, which precede/follow cold frontal passages. Strong westerly winds are infrequent at Barcelona due to topography, but 2 events of near 60 kt have been recorded in 14 yr period. Poniente winds are usually the stronger of the two, but due to a lee trough which forms along the coast, winds at Barcelona usually remain light. If Vendaval direction is south to southwest, waves may be raised in the roadstead. Vendaval may be accompanied by rain, while Poniente conditions are usually clear/clearing with possible shower activity in cold air following frontal passage.	b. Although rare, a strong event could cause difficulty for ships moored with north-south orientation, especially vessels with large sail areas. Tug assistance and additional mooring lines may be required to keep vessels on/off berths. Be aware of wind chill in winter.	b. When a storm crosses the Iberian Peninsula, the wind at Barcelona shifts from easterly clockwise to northwesterly as the storm passes. Strong westerly winds are rare at Barcelona.
Most common in Winter & early Spring Weak in Summer Autumn	c. SE'ly swell - Generated by synoptic scale SE'ly wind flow, such as Scirocco winds in warm sector of cyclone passing north of area. Swell waves refract into inner harbor through southern facing entrance and reach Muelle Sur No. 1. Normally occurs 3-5 days per year.	c. Waves which enter inner harbor can cause excessive motion to ships moored to Muelle Sur No. 1. Additional mooring lines may be required to avoid excessive motion.	c. The most likely cause of SE'ly swell at Barcelona is a synoptic scale event, such as Scirocco winds in the warm sector of cyclones passing N of the Barcelona area. The swell will diminish gradually after the wind field over the fetch area weakens or moves. With time, the swell waves will diminish in height and have shorter periods.

Table 3-5. (Continued)

VESSEL LOCATION/SITUATION	POTENTIAL HAZARD	EFFECT - PRECAUTIONARY/EVASIVE ACTIONS	ADVANCE INDICATORS AND OTHER INFORMATION ABOUT POTENTIAL HAZARD
2. Anchored in the roadstead. Strongest in Winter & early Spring Summer Autumn	a. Levante winds/waves - E'ly wind that brings the worst weather conditions to Barcelona. May result from one of several circumstances, but strongest conditions result from extratropical depressions over the Balearic Islands. May cause high winds (seldom exceed force 8 (34-40 kt)) and waves which last 3 or 4 days. Commonly accompanied by clouds, rain, and occasional thundershowers.	a. Wind and waves may create dangerous conditions in the anchorage. If high waves develop or are forecast, ships should weigh anchor and leave the roadstead. No nearby ports afford better protection. Be aware of wind chill in winter.	a. Extratropical depressions, including those that form over the Balearic Islands, sometimes move slowly and cause high winds and waves along the E coast of Spain for 3 or 4 days, sometimes longer. A low NE swell can be observed as much as 10 to 14 hr in advance of the onset. (NOTE: The NE swell can also be caused by a Mistral. See 2.d below.) Overcast skies with multiple cloud layers, rain, and thundershowers will persist as long as the wind and waves, and usually about 12 to 24 hr longer. Onshore winds may increase the water level at Barcelona by 3 ft (0.9 m), while offshore winds may decrease it by 1 ft (30 cm). Bad weather is indicated in 12 to 24 hr when the water level in the harbor lowers by 1 ft (30 cm). The weather will normally approach from the E, but at times will come from the NW. Good weather prevails when the water level remains high. NOTE: This guideline should be used with caution since a diurnal barometric tide must also be taken into account.
Most common in Winter & early Spring Autumn	b. Vendaval/Poniente winds - W'ly wind events, which precede/follow cold frontal passages. Strong westerly winds are infrequent at Barcelona due to topography, but 2 events of near 60 kt have been recorded in 14 yr period. Poniente winds are usually the stronger of the two, but due to a lee trough which forms along the coast, winds at Barcelona usually remain light. If Vendaval direction is south to southwest, waves may be raised in the roadstead. Vendaval may be accompanied by rain, while Poniente conditions are usually clear/clearing with possible shower activity in cold air following frontal passage.	b. In the rare circumstance when strong westerly winds reach the Port area, lack of fetch prevents the generation of high waves. The impact in the roadstead would be primarily that of wind; anchored ships will windcock, deployment of a second anchor may be required to prevent dragging, and small boat runs to/from the roadstead may be curtailed. If Vendaval winds are S to SW, waves may be raised in the roadstead. Be aware of wind chill during winter.	b. When a storm crosses the Iberian Peninsula, the wind at Barcelona shifts from easterly clockwise to northwesterly as the storm passes. Strong westerly winds are rare at Barcelona.
Most common in Winter & early Spring Weak in Summer Autumn	c. SE'ly winds/waves - Generated by synoptic scale SE'ly wind flow, such as Scirocco winds in warm sector of cyclone passing north of area. Swell waves refract into inner harbor through southern facing entrance and reach Muelle Sur No. 1. Normally occurs 3-5 days per year.	c. Although the roadstead is exposed to southeasterly swell, the waves are not usually high enough to pose a significant hazard to vessels in the anchorage; leaving the anchorage would not be required. In the rare circumstance when waves are high enough to cause a problem, moving to the anchorage at Pollensa Bay, Mallorca should be considered.	c. The most likely cause of SE'ly swell at Barcelona is a synoptic scale event, such as Scirocco winds in the warm sector of cyclones passing N of the Barcelona area. The swell will diminish gradually after the wind field over the fetch area weakens or moves. With time, the swell waves will diminish in height and have shorter periods.
Highest in Winter & early Spring Summer Autumn	d. NE'ly swell caused by Mistral in Gulf of Lion - Although Mistral winds do not reach the Port of Barcelona, the winds generate waves which reach the roadstead as NE'ly swell of 6 to 10 ft (2 to 3 m). The higher waves usually last for 2 to 3 hr, but may last for 6 to 12 hr. A NE'ly swell will be present at the carrier anchorage whenever a Mistral is present over the Gulf of Lion. A 40 kt Mistral will result in a swell of about 4 ft at Barcelona.	d. The roadstead is exposed to the Mistral induced swell. If the swell reaches the 6-10 ft height possible during initial onset, remaining in the anchorage may be inadvisable; especially so if the local wind direction is more-or-less perpendicular to the swell direction, so that the anchored vessels are subject to rolling. If moving to a more protected anchorage is desired, the anchorages at Palma, Mallorca (best protection) and Ibiza, Ibiza should be considered.	d. Mistral winds over the Gulf of Lion generate swell waves which may reach the Barcelona roadstead as NE 6 to 10 ft (2 to 3 m). The highest waves usually last 2 to 3 hr, but may persist for 6 to 12 hr. A NE swell will be present at the carrier anchorage whenever a Mistral is present in the Gulf of Lion. A 40 kt Mistral will produce a swell of approximately 4 ft at Barcelona.

Table 3-5. (Continued)

VESSEL LOCATION/SITUATION	POTENTIAL HAZARD	EFFECT - PRECAUTIONARY/EVASIVE ACTIONS	ADVANCE INDICATORS AND OTHER INFORMATION ABOUT POTENTIAL HAZARD
3. Arriving/departing. Strongest in Winter & early Spring Summer Autumn	a. Levante winds/waves - E'ly wind that brings the worst weather conditions to Barcelona. May result from one of several circumstances, but strongest conditions result from extratropical depressions over the Balearic Islands. May cause high winds (seldom exceed force 8 (34-40 kt)) and waves which last 3 or 4 days. Commonly accompanied by clouds, rain, and occasional thundershowers.	a. Wind may cause maneuvering problems for ships entering/leaving the inner harbor. Assistance of tug(s) may be required during berthing operations. Doubling of mooring lines may be required. Pilots may not move ships with large sail area in inner harbor in winds of force 5 (17-21 kt) or greater. Anchorage may be dangerous in a strong event. Be aware of wind chill during winter.	a. Extratropical depressions, including those that form over the Balearic Islands, sometimes move slowly and cause high winds and waves along the E coast of Spain for 3 or 4 days, sometimes longer. A low NE swell can be observed as much as 10 to 14 hr in advance of the onset. (NOTE: The NE swell can also be caused by a Mistral. See 3.d below.) Overcast skies with multiple cloud layers, rain, and thundershowers will persist as long as the wind and waves, and usually about 12 to 24 hr longer. Onshore winds may increase the water level at Barcelona by 3 ft (0.9 m), while offshore winds may decrease it by 1 ft (30 cm). Bad weather is indicated in 12 to 24 hr when the water level in the harbor lowers by 1 ft (30 cm). The weather will normally approach from the E, but at times will come from the NW. Good weather prevails when the water level remains high. NOTE: This guideline should be used with caution since a diurnal barometric tide must also be taken into account.
Most common in Winter & early Spring Autumn	b. Vendaval/Poniente winds - W'ly wind events, which precede/follow cold frontal passages. Strong westerly winds are infrequent at Barcelona due to topography, but 2 events of near 60 kt have been recorded in 14 yr period. Poniente winds are usually the stronger of the two, but due to a lee trough which forms along the coast, winds at Barcelona usually remain light. If Vendaval direction is south to southwest, waves may be raised in the roadstead. Vendaval may be accompanied by rain, while Poniente conditions are usually clear/clearing with possible shower activity in cold air following frontal passage.	b. Wind in strong event may cause maneuvering problems for ships entering/ leaving the inner harbor, but topography prevents most strong winds from affecting Barcelona. Lack of fetch restricts wave generation in inner harbor and, in most wind situations, the anchorage. Anchored vessels may windcock, deployment of second anchor may be required in a strong wind situation to prevent dragging, and small boat runs to/from the roadstead may be curtailed. Be aware of wind chill during winter.	b. When a storm crosses the Iberian Peninsula, the wind at Barcelona shifts from easterly clockwise to northwesterly as the storm passes. Strong westerly winds are rare at Barcelona.
Most common in Winter & early Spring Weak in Summer Autumn	c. SE'ly winds/waves - Generated by synoptic scale SE'ly wind flow, such as Scirocco winds in warm sector of cyclone passing north of area. Swell waves refract into inner harbor through southern facing entrance and reach Muelle Sur No. 1. Normally occurs 3-5 days per year.	c. The SE swell should pose no problems to inbound or outbound units except for inbound ships assigned a berth at Muelle Sur No. 1. If assigned such a berth and SE swell is forecast to persist, reassignment to a more protected berth should be requested.	c. The most likely cause of SE'ly swell at Barcelona is a synoptic scale event, such as Scirocco winds in the warm sector of cyclones passing N of the Barcelona area. The swell will diminish gradually after the wind field over the fetch area weakens or moves. With time, the swell waves will diminish in height and have shorter periods.
Highest in Winter & early Spring Summer Autumn	d. NE'ly swell caused by Mistral in Gulf of Lion - Although Mistral winds do not reach the Port of Barcelona, the winds generate waves which reach the roadstead as NE'ly swell of 6 to 10 ft (2 to 3 m). The higher waves usually last for 2 to 3 hr, but may last for 6 to 12 hr. A NE'ly swell will be present at the carrier anchorage whenever a Mistral is present over the Gulf of Lion. A 40 kt Mistral will result in a swell of about 4 ft at Barcelona.	d. Waves do not pose any threat to inner harbor, but the roadstead is exposed. If the swell reaches the 6-10 ft height possible during initial Mistral onset, inbound units should avoid the Barcelona anchorage and opt for an inner harbor berth, or divert to a better protected anchorage such as Palma, Mallorca (best) or Ibiza, Ibiza.	d. Mistral winds over the Gulf of Lion generate swell waves which may reach the Barcelona roadstead as NE 6 to 10 ft (2 to 3 m). The highest waves usually last 2 to 3 hr, but may persist for 6 to 12 hr. A NE swell will be present at the carrier anchorage whenever a Mistral is present in the Gulf of Lion. A 40 kt Mistral will produce a swell of approximately 4 ft at Barcelona.

Table 3-5. (Continued)

VESSEL LOCATION/SITUATION	POTENTIAL HAZARD	EFFECT – PRECAUTIONARY/EVASIVE ACTIONS	ADVANCE INDICATORS AND OTHER INFORMATION ABOUT POTENTIAL HAZARD
4. Small boats. Strongest in Winter & early Spring Summer Autumn	a. Levante winds/waves - E'ly wind that brings the worst weather conditions to Barcelona. May result from one of several circumstances, but strongest conditions result from extratropical depressions over the Balearic Islands. May cause high winds (seldom exceed force 8 (34-40 kt)) and waves which last 3 or 4 days. Commonly accompanied by clouds, rain, and occasional thundershowers.	a. Operations in the inner harbor should be largely unaffected, but wind and waves between the harbor entrance and ships in the roadstead will likely preclude safe boat operation. The wind can change directions quickly during winter, causing wind waves to cross the swell waves, creating a dangerous condition for small boats outside the harbor entrance. Be aware of wind chill during winter.	a. Extratropical depressions, including those that form over the Balearic Islands, sometimes move slowly and cause high winds and waves along the E coast of Spain for 3 or 4 days, sometimes longer. A low NE swell can be observed as much as 10 to 14 hr in advance of the onset. (NOTE: The NE swell can also be caused by a Mistral. See 4.d below.) Overcast skies with multiple cloud layers, rain, and thundershowers will persist as long as the wind and waves, and usually about 12 to 24 hr longer. Onshore winds may increase the water level at Barcelona by 3 ft (0.9 m), while offshore winds may decrease it by 1 ft (30 cm). Bad weather is indicated in 12 to 24 hr when the water level in the harbor lowers by 1 ft (30 cm). The weather will normally approach from the E, but at times will come from the NW. Good weather prevails when the water level remains high. NOTE: This guideline should be used with caution since a diurnal barometric tide must also be taken into account. It is a rule of thumb at Barcelona that anytime there is a NE swell at Barcelona in the afternoon, boating will be cancelled the next day, and for at least the following 3 days. NOTE: See Mistral guidelines below.
Most common in Winter & early Spring Autumn	b. Vendaval/Poniente winds - W'ly wind events, which precede/follow cold frontal passages. Strong westerly winds are infrequent at Barcelona due to topography, but 2 events of near 60 kt have been recorded in 14 yr period. Poniente winds are usually the stronger of the two, but due to a lee trough which forms along the coast, winds at Barcelona usually remain light. If Vendaval direction is south to southwest, waves may be raised in the roadstead. Vendaval may be accompanied by rain, while Poniente conditions are usually clear/clearing with possible shower activity in cold air following frontal passage.	b. Operations in the inner harbor should be largely unaffected in all but a rare, very strong event. Even then, wind would be the primary concern because of a lack of fetch. Operations to/from the inner harbor and anchorage may be adversely affected by a strong wind event because of the chop raised by the wind. The wind can change directions quickly during winter, causing wind waves to cross the swell waves, creating a dangerous condition for small boats outside the harbor entrance. Be aware of wind chill during winter.	b. When a storm crosses the Iberian Peninsula, the wind at Barcelona shifts from easterly clockwise to northwesterly as the storm passes. Strong westerly winds are rare at Barcelona.
Most common in Winter & early Spring Weak in Summer Autumn	c. SE'ly winds/waves - Generated by synoptic scale SE'ly wind flow, such as Scirocco winds in warm sector of cyclone passing north of area. Swell waves refract into inner harbor through southern facing entrance and reach Muelle Sur No. 1. Normally occurs 3-5 days per year.	c. The swell alone should cause no problem for small boat operation in the inner harbor except near the harbor entrance and Muelle Sur No. 1, where reflected waves may create a chop. Unless the swell were accompanied by wind waves of 2 to 3 ft or more from a more-or-less perpendicular direction, no significant problems should result outside the harbor entrance.	c. The most likely cause of SE'ly swell at Barcelona is a synoptic scale event, such as Scirocco winds in the warm sector of cyclones passing N of the Barcelona area. The swell will diminish gradually after the wind field over the fetch area weakens or moves. With time, the swell waves will diminish in height and have shorter periods.
Highest in Winter & early Spring Summer Autumn	d. NE'ly swell caused by Mistral in Gulf of Lion - Although Mistral winds do not reach the Port of Barcelona, the winds generate waves which reach the roadstead as NE'ly swell of 6 to 10 ft (2 to 3 m). The higher waves usually last for 2 to 3 hr, but may last for 6 to 12 hr. A NE'ly swell will be present at the carrier anchorage whenever a Mistral is present over the Gulf of Lion. A 40 kt Mistral will result in a swell of about 4 ft at Barcelona.	d. The swell alone should cause no problem in the inner harbor, and only minor difficulty in the roadstead.	d. Mistral winds over the Gulf of Lion generate swell waves which may reach the Barcelona roadstead as NE 6 to 10 ft (2 to 3 m). The highest waves usually last 2 to 3 hr, but may persist for 6 to 12 hr. A NE swell will be present at the carrier anchorage whenever a Mistral is present in the Gulf of Lion. A 40 kt Mistral will produce a swell of approximately 4 ft at Barcelona.
Spring Strongest in Summer Autumn	e. Sea breeze - Common occurrence at Barcelona on warm days. Begins in mid to late morning as easterly but veers as hillsides are warmed by the sun, becoming southwesterly by late afternoon. Commonly attains force 3-4 (7-10 to 11-16 kt) but may reach force 5-6 (17-21 to 22-27 kt) in strong event. May raise seas to 3 ft (0.9 m) in the roadstead. Dies quickly after sunset.	e. The sea breeze alone should cause no problem in any portion of the Port, but the seas raised by the wind may cause some minor difficulties for small boats making runs to/from vessels in the roadstead. When possible, such runs should be made before mid to late afternoon, when the wind force is at its strongest.	e. A sea breeze will occur on most warm days, with the strongest force occurring on warm days when the sea breeze directions coincide with the wind flow prevailing over the area. The sea breeze is least likely to occur during November, December, January, and February.

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PORT VISIT INFORMATION

MAY 1987. NEPRF meteorologists D. Perryman and R. Miller met with the Chief Pilot and Senior Pilot to obtain much of the information used in this port evaluation.

APPENDIX A

General Purpose Oceanographic Information

This section provides general information on wave forecasting and wave climatology as used in this study. The forecasting material is not harbor specific. The material in paragraphs A.1 and A.2 was extracted from H.O. Pub. No. 603, Practical Methods for Observing and Forecasting Ocean Waves (Pierson, Neumann, and James, 1955). The information on fully arisen wave conditions (A.3) and wave conditions within the fetch region (A.4) is based on the JONSWAP model. This model was developed from measurements of wind wave growth over the North Sea in 1973. The JONSWAP model is considered more appropriate for an enclosed sea where residual wave activity is minimal and the onset and end of locally forced wind events occur rapidly (Thornton, 1986), and where waves are fetch limited and growing (Hasselmann, et al., 1976). Enclosed sea, rapid onset/subsiding local winds, and fetch limited waves are more representative of the Mediterranean waves and winds than the conditions of the North Atlantic from which data was used for the Pierson and Moskowitz (P-M) Spectra (Neumann and Pierson 1966). The P-M model refined the original spectra of H.O. 603, which over developed wave heights.

The primary difference in the results of the JONSWAP and P-M models is that it takes the JONSWAP model longer to reach a given height or fully developed seas. In part this reflects the different starting wave conditions. Because the propagation of waves from surrounding areas into semi-enclosed seas, bays, harbors, etc. is limited, there is little residual wave action following periods of locally light/calm winds and the sea surface is nearly flat. A local wind developed wave growth is therefore slower than wave growth in the open ocean where some residual wave action is generally always

present. This slower wave development is a built in bias in the formulation of the JONSWAP model which is based on data collected in an enclosed sea.

A.1 Definitions

Waves that are being generated by local winds are called "SEA". Waves that have traveled out of the generating area are known as "SWELL". Seas are chaotic in period, height and direction while swell approaches a simple sine wave pattern as its distance from the generating area increases. An in-between state exists for a few hundred miles outside the generating area and is a condition that reflects parts of both of the above definitions. In the Mediterranean area, because its fetches and open sea expanses are limited, SEA or IN- BETWEEN conditions will prevail. The "SIGNIFICANT WAVE HEIGHT" is defined as the average value of the heights of the one-third highest waves. PERIOD and WAVE LENGTH refer to the time between passage of, and distances between, two successive crests on the sea surface. The FREQUENCY is the reciprocal of the period ($f = 1/T$) therefore as the period increases the frequency decreases. Waves result from the transfer of energy from the wind to the sea surface. The area over which the wind blows is known as the FETCH, and the length of time that the wind has blown is the DURATION. The characteristics of waves (height, length, and period) depend on the duration, fetch, and velocity of the wind. There is a continuous generation of small short waves from the time the wind starts until it stops. With continual transfer of energy from the wind to the sea surface the waves grow with the older waves leading the growth and spreading the energy over a greater range of frequencies. Throughout the growth cycle a SPECTRUM of ocean waves is being developed.

A.2 Wave Spectrum

Wave characteristics are best described by means of their range of frequencies and directions or their spectrum and the shape of the spectrum. If the spectrum of the waves covers a wide range of frequencies and directions (known as short-crested conditions), SEA conditions prevail. If the spectrum covers a narrow range of frequencies and directions (long crested conditions), SWELL conditions prevail. The wave spectrum depends on the duration of the wind, length of the fetch, and on the wind velocity. At a given wind speed and a given state of wave development, each spectrum has a band of frequencies where most of the total energy is concentrated. As the wind speed increases the range of significant frequencies extends more and more toward lower frequencies (longer periods). The frequency of maximum energy is given in equation 1.1 where v is the wind speed in knots.

$$f_{max} = \frac{2.476}{v} \qquad (1.1)$$

The wave energy, being a function of height squared, increases rapidly as the wind speed increases and the maximum energy band shifts to lower frequencies. This results in the new developing smaller waves (higher frequencies) becoming less significant in the energy spectrum as well as to the observer. As larger waves develop an observer will pay less and less attention to the small waves. At the low frequency (high period) end the energy drops off rapidly, the longest waves are relatively low and extremely flat, and therefore also masked by the high energy frequencies. The result is that 5% of the upper frequencies and 3% of the lower frequencies can be cut-off and only the remaining

frequencies are considered as the "significant part of the wave spectrum". The resulting range of significant frequencies or periods are used in defining a fully arisen sea. For a fully arisen sea the approximate average period for a given wind speed can be determined from equation (1.2).

$$\bar{T} = 0.285v \qquad (1.2)$$

Where v is wind speed in knots and T is period in seconds. The approximate average wave length in a fully arisen sea is given by equation (1.3).

$$\bar{L} = 3.41\ \bar{T}^2 \qquad (1.3)$$

Where $\bar{L}$ is average wave length in feet and $\bar{T}$ is average period in seconds.

The approximate average wave length of a fully arisen sea can also be expressed as:

$$\bar{L} = .67\text{"L"} \qquad (1.4)$$

where "L" = $5.12T^2$, the wave length for the classic sine wave.

A.3 Fully Arisen Sea Conditions

For each wind speed there are minimum fetch (n mi) and duration (hr) values required for a fully arisen sea to exist. Table A-1 lists minimum fetch and duration values for selected wind speeds, values of significant wave (average of the highest 1/3 waves) period and height, and wave length of the average wave during developing and fully arisen seas. The minimum duration time assumes a start from a flat sea. When pre-existing

lower waves exist the time to fetch limited height will be shorter. Therefore the table duration time represents the maximum duration required.

Table A-1. Fully Arisen Deep Water Sea Conditions Based on the JONSWAP Model.

Wind Speed (kt)	Minimum Fetch/Duration (n mi) (hrs)	Sig Wave (H1/3) Period/Height (sec) (ft)	Wave Length (ft)[1,2] Developing/Fully /Arisen L X (.5) /L X (.67)
10	28 / 4	4 / 2	41 / 55
15	55 / 6	6 / 4	92 / 123
20	110 / 8	8 / 8	164 / 220
25	160 / 11	9 / 12	208 / 278
30	210 / 13	11 / 16	310 / 415
35	310 / 15	13 / 22	433 / 580
40	410 / 17	15 / 30	576 / 772

NOTES:

[1] Depths throughout fetch and travel zone must be greater than 1/2 the wave length, otherwise shoaling and refraction take place and the deep water characteristics of waves are modified.

[2] For the classic sine wave the wave length (L) equals 5.12 times the period (T) squared ($L = 5.12T^2$). As waves develop and mature to fully developed waves and then propagate out of the fetch area as swell their wave lengths approach the classic sine wave length. Therefore the wave lengths of developing waves are less than those of fully developed waves which in turn are less than the length of the resulting swell. The factor of .5 (developing) and .67 (fully developed) reflect this relationship.

A.4 Wave Conditions Within The Fetch Region

Waves produced by local winds are referred to as SEA. In harbors the local sea or wind waves may create hazardous conditions for certain operations. Generally within harbors the fetch lengths will be short and therefore the growth of local wind waves will be fetch limited. This implies that there are locally determined upper limits of wave height and period for each wind velocity. Significant changes in speed or direction will result in generation of a new wave group with a new set of height and period limits. Once a fetch limited sea reaches its upper limits no further growth will occur unless the wind speed increases.

Table A-2 provides upper limits of period and height for given wind speeds over some selected fetch lengths. The duration in hours required to reach these upper limits (assuming a start from calm and flat sea conditions) is also provided for each combination of fetch length and wind speed. Some possible uses of Table A-2 information are:

1) If the only waves in the area are locally generated wind waves, the Table can be used to forecast the upper limit of sea conditions for combinations of given wind speeds and fetch length.

2) If deep water swell is influencing the local area in addition to locally generated wind waves, then the Table can be used to determine the wind waves that will combine with the swell. Shallow water swell conditions are influenced by local bathymetry (refraction and shoaling) and will be addressed in each specific harbor study.

3) Given a wind speed over a known fetch length the maximum significant wave conditions and time needed to reach this condition can be determined.

Table A-2. Fetch Limited Wind Wave Conditions and Time Required to Reach These Limits (Based on JONSWAP Model). Enter the table with wind speed and fetch length to determine the significant wave height and period, and time duration needed for wind waves to reach these limiting factors. All of the fetch/speed combinations are fetch limited except the 100 n mi fetch and 18 kt speed.

Format: height (feet)/period (seconds)
duration required (hours)

Fetch \ Length \ (n mi)	Wind Speed (kt) 18	24	30	36	42
10	2/3-4 1-2	3/3-4 2	3-4/4 2	4/4-5 1-2	5/5 1-2
20	3/4-5 2-3	4/4-5 3	5/5 3	6/5-6 3-4	7/5-6 3
30	3-4/5 3	5/5-6 4	6/6 3-4	7/6 3-4	8/6-7 3
40	4-5/5-6 4-5	5/6 4	6-7/6-7 4	8/7 4	9-10/7-8 3-4
100	5/6-7[1] 5-6	9/8 8	11/9 7	13/9 7	15-16/9-10 7

[1] 18 kt winds are not fetch limited over a 100 n mi fetch.

An example of expected wave conditions based on Table A-2 follows:

WIND FORECAST OR CONDITION

An offshore wind of about 24 kt with a fetch limit of 20 n mi (ship is 20 n mi from the coast) is forecast or has been occurring.

SEA FORECAST OR CONDITION

From Table A-2: If the wind condition is forecast to last, or has been occurring, for at least 3 hours:

Expect sea conditions of 4 feet at 4-5 second period to develop or exist. If the condition lasts less than 3 hours the seas will be lower. If the condition lasts beyond 3 hours the sea will not grow beyond that developed at the end of about 3 hours unless there is an increase in wind speed or a change in the direction that results in a longer fetch.

A.5 Wave Climatology

The wave climatology used in these harbor studies is based on 11 years of Mediterranean SOWM output. The MED-SOWM is discussed in Volume II of the U.S. Naval Oceanography Command Numerical Environmental Products Manual (1986). A deep water MED-SOWM grid point was selected as representative of the deep water wave conditions outside each harbor. The deep water waves were then propagated into the shallow water areas. Using linear wave theory and wave refraction computations the shallow water climatology was derived from the modified deep water wave conditions. This climatology does not include the local wind generated seas. This omission, by design, is accounted for by removing all wave data for periods less than 6 seconds in the climatology. These shorter period waves are typically dominated by locally generated wind waves.

A.6 Propagation of Deep Water Swell Into Shallow Water Areas

When deep water swell moves into shallow water the wave patterns are modified, i.e., the wave heights and directions typically change, but the wave period remains constant. Several changes may take place including shoaling as the wave feels the ocean bottom, refraction as the wave crest adjusts to the bathymetry pattern, changing so that the crest becomes more parallel to the bathymetry contours, friction with the bottom sediments, interaction with currents, and adjustments caused by water temperature gradients. In this work, only shoaling and refraction effects are considered. Consideration of the other factors are beyond the resources available for this study and, furthermore, they are considered less significant in the harbors of this study than the refraction and shoaling factors.

To determine the conditions of the deep water waves in the shallow water areas the deep water

conditions were first obtained from the Navy's operational MED-SOWM wave model. The bathymetry for the harbor/area of interest was extracted from available charts and digitized for computer use. Figure A-1 is a sample plot of bathymetry as used in this project. A ray path refraction/shoaling program was run for selected combinations of deep water wave direction and period. The selection was based on the near deep water wave climatology and harbor exposure. Each study area requires a number of ray path computations. Typically there are 3 or 4 directions (at 30° increments) and 5 or 6 periods (at 2 second intervals) of concern for each area of study. This results in 15 to 24 plots per area/harbor. To reduce this to a manageable format for quick reference, specific locations within each study area were selected and the information was summarized and is presented in the specific harbor studies in tabular form.

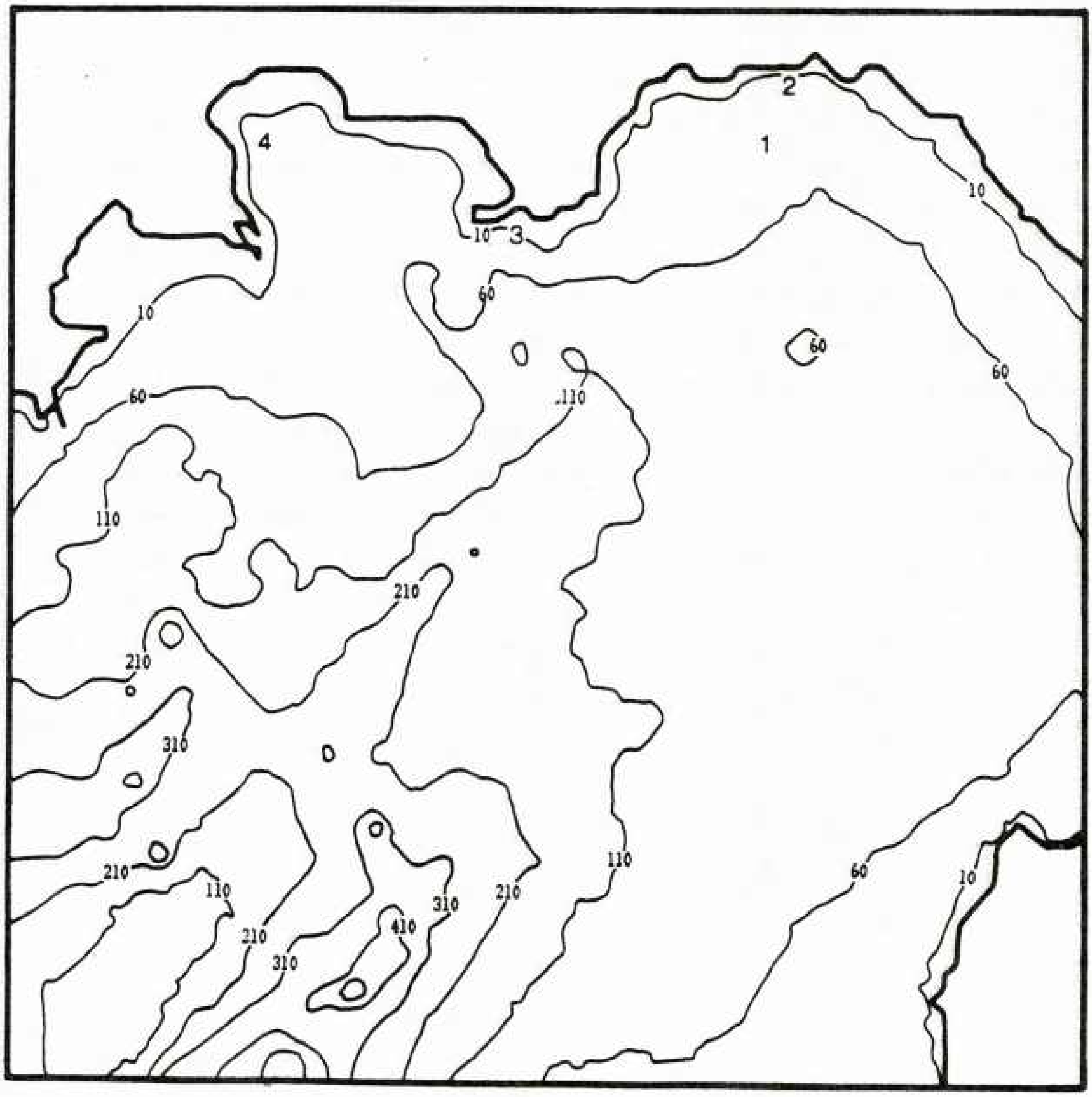

Figure A-1. Example plot of bathymetry (Naples harbor) as used in this project. For plotting purposes only, contours are at 50 fathom intervals from an initial 10 fathoms to 110 fathoms, and at 100 fathom intervals thereafter. The larger size numbers identify specific anchorage areas addressed in the harbor study.

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RUE DU CHATELLIER, B.P. 426
29275 - BREST CEDEX, FRANCE

METEOROLOGIE NATIONALE
1 QUAI BRANLY
75, PARIS (7)
FRANCE

DIRECTION DE LA METEOROLOGIE
ATTN: J. DETTWILLER, MN/RE
77 RUE DE SEVRES
92106 BOULOGNE-BILLANCOURT
CEDEX, FRANCE

OZEANOGRAPHISCHE
FORSCHUNGSANTALT BUNDESWEHR
LORNSENSTRASSE 7, KIEL
FEDERAL REPUBLIC OF GERMANY

INSTITUT FUR MEERESKUNDE
AN DER UNIVERSITAT KIEL
DUSTERNBROOKER WEG 20
23 KIEL
FEDERAL REPUBLIC OF GERMANY

INSTITUT FUR MEERESKUNDE DER
UNIVERSITAT HAMBURG
HEIMHUDERSTRASSE 71
2000 HAMBURG 13
FEDERAL REPUBLIC OF GERMANY

DIRECTOR, DEUTSCHES
HYDROGRAPHISCHES INSTITUT
TAUSCHSTELLE, POSTFACH 220
D2000 HAMBURG 4
FEDERAL REPUBLIC OF GERMANY

ISTITUTO UNIVERSITARIO NAVALE
FACILTA DI SCIENZE NAUTICHE
ISTITUTO DI METEOROLOGIA E
OCEANOGRAFIA, 80133 NAPOLI -
VIA AMM, ACTON, 38 ITALY

CONSIGLIO NAZIONALE DELLE
RICERCHE
ISTITUTO TALASSOGRAFICO DI
TRIESTE, VIALE R. GESSI 2
34123 TRIESTE, ITALY

DIRECTOR, SACLANT ASW
RESEARCH CENTRE
VIALE SAN BARTOLOMEO, 400
I-19026 LA SPEZIA, ITALY